Central Plains Experimental Range Long Term Ecological Research Project

1993 Annual Report

The Central Plains Experimental Range Long Term Ecological Research Project was first funded in 1982. In the past 11 years, the project has supported a large number of studies. Since nearly all of these studies are long-term in nature, it is appropriate to summarize not only new activities, but also the continuing projects within the research program.

We have organized our report into 5 key areas: Core Area Research, Synthesis Activities, Current International Collaborations, Interactions with other Projects, and Data Management.

1. CORE AREAS

a. Pattern and control of primary production

Our significant research on primary productivity has addressed questions of 'controls and patterns' at both site and regional levels as well as at analytical/statistical and methodological levels. We grouped these findings based into aboveground (ANPP) and belowground (BNPP) production, and methodological sections.

<u>Aboveground</u>

1.) Four locations at the CPER have been sampled for ANPP since 1982; five since 1986. Sampling locations were selected to represent topographic positions (summit, backslope, and swale) in conjunction with sampling of soilwater. Two additional sites were selected from IBP sample sites. This year we have synthesized these data to report the following findings:

a.) The effects of long-term grazing on ANPP depend upon precipitation in a particular year interacting with the intensity of the grazing (Varnamkhasti et al. 1993, Milchunas et al. 1993a,b,, Milchunas and Lauenroth 1993). However, current-year defoliation increases water-use-efficiency, ANPP (Varnamkhasti et al. 1993), and nitrogen- and digestible-forage-yield (Milchunas et al. 1993b).

b.) Analysis of long-term forage production from 1943 to 1983 indicated average forage production to be 67 g/m^2 with a standard deviation of 23 g/m^2. Because forage production represents 60% of ANPP at the CPER, average ANPP for the same period was 110 g/m^2. A comparison of variables of production and precipitation using coefficients of variation indicate that production (CV=34%) was slightly more variable than precipitation (CV=30%).

The two variables were highly correlated. Long-term production was not related to temperature; annual and seasonal precipitation and the size of rainfall events account for much of the variability.

2). In 1992, we initiated a new long-term study of the effects of grazing on ecosystem structure and function in shortgrass steppe (see CORE AREA: DISTURBANCE). As a part of this experiment, we are sampling net primary production in all treatments. Data from this study will support a product 2-3 years after the experiment was initiated.

3.) Our remote sensing research activities currently being conducted are significantly enhanced by the existence of the long term grazing exclosures and the ongoing assessment of above ground biomass at specific locations within these exclosures and at various grazed sites. We were able to use a GPS (Global Positioning Receiver) to determine the precise Latitude/Longitude location of these field sample sites and then define these same locations on the Landsat satellite data with a high degree of accuracy and confidence in the resulting data set. This allowed us to study various potential relationships between vegetation indices developed using the satellite data and the actual above ground biomass (Todd, Hoffer, and Milchunas 1993).

<u>Belowground</u>

1.) We have invested significant effort in estimating belowground production in a long-term C-14 tracer study. This work has recently revised our perceptions of the importance of carbon input to soil via root turnover. Root biomass at the CPER can be as much as 90% of total biomass, but turnover-times of 5 to 7 yrs for roots and 8 yrs for crowns yield estimates of production below those obtained by old traditional methods (Milchunas and Lauenroth 1992). Carbon input to soil via exudation is significant.

<u>Methodological</u>

1.) Simulation modeling has demonstrated the potential for large errors of estimating production when using traditional methods (Singh et al. 1984, Lauenroth et al. 1986). We developed an analytical solution to the problem of calculating production (Sala et al. 1988). Random errors associated with estimates of biomass used in calculation of net production always have the effect of overestimating net production. The overestimation was related to sampling effort in such a way that the more times biomass was estimated, the higher the overestimate. A method was also developed to correct net production values for the overestimation (Biondini et al. 1991). This problem has been addressed by developing isotope-turnover methods of estimating ANPP, BNPP, and crown production (Milchunas et al. 1985, Milchunas et al. 1992).

List of recent products regarding primary production:

Biondini, M.E., W.K. Lauenroth, and O.E. Sala. 1991. Correcting estimates of net primary production: Are we overestimating plant production in rangelands. J. Range Manage. 44:194-198.

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

Milchunas D. G., J. R. Forwood, and W. K. Lauenroth. 1993. Forage production across fifty years of grazing intensity treatments in shortgrass steppe. J. Range Manage. (in press).

Milchunas, D. G. and W. K. Lauenroth. 1993. A quantitative assessment of the effects of grazing on vegetation and soils over a global range of environments. Ecological Monographs (in press).

Milchunas, D. G. and W. K. Lauenroth. 1992. Carbon dynamics and estimates of primary production by harvest, C^{14} dilution, and ^{14}C turnover. Ecology 73:593-607.

Todd, S., R. Hoffer, D. G. Milchunas. 1993. Comparison of four vegetation indices for estimating aboveground biomass on grazed and ungrazed rangeland. Proceedings 1993 ASPRS-ACMS Annual Meeting, February 16-19, 1993, New Orleans, LA.

Varnamkhasti, Amrali S. 1991. Aboveground production and rain use efficiency responses to long-term grazing, defoliation, and rainfall. Master's Thesis. Dept Range Science, Colorado State Univ. (Advisor: H. Goetz)

Varnamkhasti, A. S., D. G. Milchunas, W. K. Lauenroth, and H. Goetz. 1993. Interactions between grazing history, defoliation, and precipitation: 1) aboveground production and rain use efficiency. Oecologia (submitted).

b. Spatial and temporal distribution of populations selected to represent trophic structure

Our significant research on populations has focused on both plants and animals.

Plant populations

Physiognomy as well as trophic structure of shortgrass steppe ecosystems are dominated by the perennial bunchgrass, Bouteloua gracilis. Our plant population work has focused on the interactions of disturbance size, frequency, and type, with recruitment and mortality of B. gracilis as well as abiotic and biotic controls over demographic variables of this and other species.

1.) Bouteloua gracilis population dynamics

(a) We recently synthesized some of our understanding of the population dynamics of Bouteloua gracilis (Coffin and Lauenroth 1990). Much of our recent focus in LTER has been an individual-plant based approach to studying population dynamics, especially for B. gracilis. We have conducted a number of studies evaluating the recruitment and mortality of individual B. gracilis plants. No quantitative information on seed production of this species was available prior to the study reported in this paper. In this study, we evaluated the effects of soil texture and grazing by cattle on seed production of individual plants. Our results indicate that the production of viable seeds is negatively related to the clay content of the soil; a result consistent with the hypothesized inverse-texture effect on plant production. The relationship between seed production and clay content was different for ungrazed and grazed sites, where grazing mediated the effect of soil texture. Temporal variability in seed production is also being monitored by collecting data annually at these ten sites since 1989. The observed spatial and temporal variability in production of viable seeds suggests that seed production is an important constraint on the ability of B. gracilis to recover after disturbances.

(b) A field study was initiated in 1991 to evaluate the response of individual B. gracilis plants to small (0.1 to 0.3 m-diameter) disturbances, and the effects of soil texture and disturbance type on plant mortality. Plant mortality occurred only if the entire plant was removed or shaded. Removing or shading parts of individual plants resulted in tiller mortality, but not plant mortality. This work is in in prep (Fair, Thesis in prep).

(c) A simulation analysis using a multi-layer daily timestep model of soil water dynamics (SOILWAT) indicated that establishment of B. gracilis seedlings is affected by soil texture where the probability of establishment increases as the silt content of the soil increases. Recruitment events occur as frequently as every 50 years on silty clay, silty clay loam, and silty loam soils, and less than once in 5000 years on sandy soils (Lauenroth et al. submitted).

(d) We conducted a series of experiments designed to evaluate the effects of neighborhood interactions in steady state populations of B. gracilis. Results suggested that established adults are very important sources of competition for seedling and may in many cases explain the failure of most seedlings to become established (Aguilera 1992, Aguilera and Lauenroth 1993a,b).

(e) We recently initiated a study to evaluate the intra- and inter-specific competitive interactions between B. gracilis, and another important C4 perennial grass in shortgrass ecosystems, Buchloe dactyloides (buffalograss). Plots containing mixtures or pure stands of these species are receiving one of four treatments: 1) supplemental water, 2) supplemental nitrogen, 3) supplemental water and nitrogen, and 4) control plots containing no supplemental water or nitrogen. Preliminary results indicate that biomass accumulation and reproductive output are reduced under conditions of intra- and inter-specific competition for both species, but intensity and importance of competition were different for both species (Aguiar et al. 1993).

Animal populations

1.) Roadside censuses along a permanent transect are being used to evaluate seasonal and interannual fluctuations in bird populations. Nesting behavior of the Horned Lark, McGown's Longspur, and Lark Bunting as well as movement patterns of McGown's Longspur and their important prey item, grasshoppers, are also being studied (With, in prep).

2.) Habitat use and activity of the grasshopper mouse (Onychomys leucogaster) and the deer mouse (Peromyscus maniculatus) are being studied using radiotelemetry methods (Stapp, in prep).

3.) June beetles (Phyllophaga sp.) represent one of the most important populations of herbivores because of their effects on the system rather than as a result of their abundance. The larval stage of Phyllophaga feeds on roots of B. gracilis, which in certain years results in widespread but patchy death of individuals. Populations of adults have been monitored since 1986 using light traps. Year-to-year fluctuations in density of adults are large, ranging from peaks of 40 to 360/week.

4.) We recently produced a synthesis of our plant and animal population research (Lauenroth and Milchunas 1992). This chapter is a broad overview of the shortgrass steppe region in North America. This chapter represents the best synthesis of our plant and animal population research. Plant, animal, arthropod, and microbial population data were compiled.

List of recent products regarding populations:

Aguiar, M., W.K. Lauenroth, and D.P. Coffin. 1993. Intensity and importance of inter- and intraspecific competition between C_4 perennial grasses. Bull. of Ecol. Soc. of Amer. 74:2

Aguilera, M. O. Intraspecific interactions in blue grama. Ph.D. Dissertation. Range Science Dept., Colorado State Univ. 1992. (Advisor: W.K. Lauenroth)

Aguilera, M.O. and W.K. Lauenroth. 1993a. Seedling establishment in adult neighbourhoods--intraspecific constraints in the regeneration of the bunchgrass *Bouteloua gracilis.* J. Ecology 81:253-261.

Aguilera, M.O. and W.K. Lauenroth. 1993b. Neighborhood interactions in a natural population of the perennial bunchgrass *Bouteloua gracilis*. Oecologia (in press).

Aguilera, M.O. and W.K. Lauenroth. Allocation and inequality in a native population of *Bouteloua gracilis*. Oikos (submitted).

Aguilera, M.O. and W.K. Lauenroth. Influence of gap disturbance and type of microsites on seedling establishment in *Bouteloua gracilis*. J. Ecol. (submitted).

Coffin, D. P., and W. K. Lauenroth. 1992. Spatial variability in seed production of the perennial bunchgrass B. gracilis (Gramineae). American Journal of Botany 79: 347-353.

Fair, J.L., D.P. Coffin, and W.K. Lauenroth. 1993. Demography of individual blue grama (*Bouteloua gracilis*) plants: A GIS analysis of genets and population dynamics. Bull of the Ecol. Soc. of Amer. 74:2.

Holland, E.A., W.J. Parton, J.K. Detling, and D.L. Coppock. 1992. Physiological responses of plant populations to herbivory and their consequences for ecosystem nutrient flow. Amer. Nat. (in press).

Hunt, H.W., E.T. Elliott, J.K. Detling, C.A. Monz, and D.E. Reuss. 1992. Plant size and shoot to root ratio in intact sods of native shortgrass prairie exposed to elevated CO_2 for two growing seasons. Bull. of Ecol. Soc. of Amer. 73:2.

Lauenroth, W.K., D.P. Coffin, and I.C. Burke. 1992. Alternative ways to be a dominant perennial grass: population and ecosystem consequences. IGBP Global Change Workshop on Functional Types. Univ. of Virginia, Charlottesville, VA.

Lauenroth, W. K., and D. G. Milchunas. 1992. The shortgrass steppe. In, Natural Grasslands (R. T. Coupland, ed.). Elsevier, NY.

Lauenroth, W. K., O. E. Sala, D. P. Coffin, and T. B. Kirchner. Establishment of Bouteloua gracilis in the shortgrass steppe. Ecological Applications (submitted).

Lee, C.A. and W.K. Lauenroth. Spatial distributions of grass and shrub root systems in the shortgrass steppe. Amer. Midl. Nat. (in press).

Milchunas, D.G., C.A. Lee, W.K. Lauenroth, and D.P. Coffin. 1992. A comparison of ^{14}C, ^{86}Rb, and total excavation for determination of root distributions of individual plants. Plant and Soil 144:125-132.

Moore, J.C. and P.C. DeRuiter. 1993. Assessment of disturbance on soil ecosystems. J. Vet Parasit. 48:75-85.

Moore, J.C., P.C. DeRuiter, and H.W. Hunt. 1993. Soil invertebrate/micro-invertebrate interactions: disproportionate effects of species on food web structure and function. J. Vet. Parasit. 48:247-260.

Moore, J.C., P.C. DeRuiter, and H.W. Hunt. 1993. Influence of productivity on the stability of real and model ecosystems. Science. 261:906-908.

Zak, D. R., D. Tilman, R. Parmenter, F. M. Fisher, C. Rice, J. Vose, D. Milchunas, C. W. Martin. Constraints on the activities of soil microorganisms along a gradient of climate and plant production in North America. Ecology (submitted).

c. Pattern and control of organic matter accumulation and of inorganic inputs and movements of nutrients

In semiarid regions, the inputs and movements of nutrients are closely tied to the inputs and fate of soil organic matter, therefore, our approach is to deal with them together. Our significant research in these areas has focused on spatial heterogeneity and its causes at individual plant, catena, and physiographic scales, and has most recently explicitly addressed the influence of recovery from disturbance on soil organic matter and nutrient dynamics.

Spatial heterogeneity

1). A field study was initiated in 1992 to evaluate the influence of plant species and plant functional groups on patterns in soil organic matter and nutrient availability (Vinton and Burke, in prep). We found that functional groups are more important than species identity, with perennial bunchgrasses causing the greatest small-scale heterogeneity, and annual herbaceous species the least.

2) A field study was initiated in 1992 to compare species-ecosystem interactions such as those described above across a climatic gradient including CPER, Hays, KS, and Konza (Vinton and Burke, in prep).

3) We have recently begun a new area of work that focuses on soil-climate interactions. The goal of this work is to understand the climatic and biological conditions that existed during the Holocene in the central Great Plains region. We suggest that studies of past climates and ecosystems are critical to our understanding of present-day systems, and provide important tests of our abilities to use the present as an example of distant future or past systems. Our first manuscript (Kelly et al. 1993) summarizes our results regarding the paleoclimatic significance and isotope geochemistry of buried land surfaces (paleosols) in the central Great Plains region. This work reports that isotopic techniques can be used over short (Holocene) pedologic time intervals to provide "high resolution" paleoenvironmental information. Results from our intensive isotopic characterization (stable and radiometric isotopes)

of organic matter, carbonate, and opal phytoliths helped us identify three distinct soil forming periods interrupted by drought during the Holocene. The pattern of general warming of the regional climate supports earlier research results (Kelly et al, 1991a, 1991b). The results of this work reinforce our idea that we can reconstruct the terrestrial climatic record through the use of paleosols.

Work that is in preparation covers the importance of landscape evolution and paleovegetation and the close link between the two. This paleotopographic reconstruction has proven valuable for interpreting paleoclimatic data derived from paleosols and will prove critical to our studies in other regions. For example, an application of these techniques to the Palouse paleosols would allow us to push this technique back chronologically.

4) We continue to collect data for the National Atmospheric Deposition Program (NADP) at our site. We collect wet- and dry-fall samples for complete chemical analysis.

5). During the summer of 1992, we initiated a field study on 3 abandoned fields in the CPER that contain grazing exclosures. We are assessing the interactions between grazing, plant population recovery, and soil organic matter recovery dynamics (including N mineralization) in native field, and in the abandoned fields both inside and outside the exclosures. (Coffin et al in prep, Burke et al in prep).

6). Since the initiation of LTER III, we have begun a large scale study on the influence of grazing and protection from grazing on a number of key ecological phenomena, including soil organic matter. Initial data indicate that exclosures have higher soil organic matter than long-term grazed plots. We are moving exclosures to test whether grazing imposes a system-level degradation of soil organic matter (and other features), or exclosure causes system aggradation. See disturbance section for more description of this work.

7). In 1989, we initiated a long-term ^{15}N study to investigate the influence of grazing and exclosure on organic matter dynamics across a toposequence. We resampled in 1992 (Hook et al. in prep), and anticipate sampling at long time intervals throughout the lifetime of LTER.

8). In 1992, we initiated a seasonal study of the interactions between seasonal precipitation and field N mineralization rates. This study is being conducted across a number of landscape positions (Hook and Burke, in prep).

9) In 1990, we conducted a study of recovering fields in northeastern Colorado. This paper is currently submitted to Ecological Applications. This paper presents results of a very recent study that focuses on the recovery dynamics of soil organic matter from cultivation at the CPER and in the shortgrass steppe surrounding the CPER. We feel that it will be a significant contribution to the literature on grassland recovery because

it indicates the crucial interaction of plant recovery dynamics and soil organic matter recovery. The results indicate that B. gracilis establishment is necessary for the recovery of "active" pools of soil organic matter important to nutrient supply capacity. In addition, the results indicate that 50 years is sufficient for the recovery of these active pools, but not for significant recovery of total soil organic matter pools.

List of recent products regarding nutrients/organic matter:

Blecker, S. W. 1993. Pedologic and geologic indicators of Holocene environments in the Colorado Piedmont. M.S. Thesis. Department of Agronomy, Colorado State University, Fort Collins, CO. (Advisor: E. F. Kelly).

Burke, I. C., W. K. Lauenroth, and D. P. Coffin. Response of a semiarid grassland to large-scale disturbance: Recovery of soil organic matter and nutrient supply capacity. Submitted to Ecological Applications.

Hook, P.B., W.K. Lauenroth, and I.C. Burke. 1993. Spatial patterns of water, roots, and organic matter in shortgrass steppe: an individual-plant perspective on ecosystem dynamics. Bull. of Ecol. Soc. of Amer. 74(2) Program & Abstracts, 78th Annual ESA Meeting. Madison, WI.

Hook, P. B., W. K. Lauenroth, and I. C. Burke. Spatial patterns of plant cover and roots in a semiarid grassland: abundance of canopy openings, root gaps, and resource gaps. Submitted to J. Ecol.

Ihori, T., and I. C. Burke. Effects of disturbance and recovery on small-scale heterogeneity of in situ N mineralization in semiarid grassland soils. Submitted to Plant and Soil.

Ihori, T., I. C. Burke, W. K. Lauenroth, and D. P. Coffin. Effects of cultivation and recovery on soil organic matter in northeastern Colorado. Submitted to Soil Science Society of America Journal.

Kelly, E.F., Marino, B.D, Yonker, C. M. 1993. The Stable Carbon Isotope Composition of Paleosols: An Application to the Holocene. J. of Geophys. Res. (In press)

Sala, O.E., W.K. Lauenroth, and I.C. Burke. 1992. Carbon balance of temperate grasslands. SCOPE Workshop. Upsala, Sweden September 1992.

Schimel, D.S., D.S. Ojima, E.A. Holland, and W.J. Parton. 1993. Climatic and edaphic controls over carbon turnover in mineral soils: simulations and validation. Bull. of Ecol. Soc. of Amer. 74:2.

Vinton, M.A. and I.C. Burke. 1993. Interactions between plant species and soil nutrient status in a shortgrass steppe. Bull. of Ecol. Soc. of Amer. 74:2.

Vinton, M. A. V., and I. C. Burke. Interactions of plant species and resource availability in shortgrass steppe. In prep, to be submitted to Ecology.

d. Water dynamics

We have designated Water Dynamics as an additional core topic because we consider it to be fundamental for understanding the origin, structure and function, and sustainability of the shortgrass steppe. Research under other core topics includes analyses of the interactions between water and primary production, organic matter and nutrients, vegetation structure and dynamics, and effects of disturbance. The key questions about water dynamics concern variation in the major external control of water, precipitation, and variation in the major, proximate control of ecosystem processes, soil water.

From the start of the LTER Program, our conceptual model has emphasized two ideas. First, precipitation is highly variable between years and occurs in unpredictable pulses within years. Only the fact that most precipitation occurs during the summer growing season is predictable. Second, availability of water for ecological processes is modified by soil texture and topography. During LTER, we have made major progress in gathering solid empirical support for these ideas, developing more sophisticated ideas about the ecological consequences of the variability of water, and developing simulation models to estimate long-term soil water dynamics and its ecological consequences.

1). We recently produced a paper that integrates our long-term meteorological records with simulation analysis to evaluate a long-term estimate of soil water dynamics (Sala et al. 1992). Sala, O.E., W.K. Lauenroth, and W.J. Parton. 1992. It represents a major step towards (1) systematically describing the temporal variability in precipitation and soil water between years and within growing seasons and (2) describing differences in dynamics of water at different soil depths and their relation to precipitation. In other words, it summarizes our understanding of patterns and controls of water dynamics in the shortgrass steppe. Precipitation is concentrated during the growing season. Small precipitation events, which wet surface soil, are most frequent and occur in similar amounts in most years. Water from small rains is lost rapidly. Consequently, surface soil is usually dry and shows no seasonal pattern. Large rainfall events, which can infiltrate deeper, occur infrequently and are responsible for most of the difference between wet and dry years. Intermediate soil layers have highest soil water availability over the year and show a strong seasonal pattern related to spring and summer precipitation. Soil water is concentrated very near the surface in dry years and percolates up to 1.3 m deep in wet years. The shallow modal distribution of soil water matches the distributions of roots of the dominant grass, B. gracilis, providing support for the hypothesized basis for dominance of B. gracilis and its coexistence with other species. Interaction of soil water distribution and biotic constraints may determine the distributions and rates of ecosystem processes controlling organic matter and nutrients. Results demonstrate the need to focus efforts on understanding water dynamics near the soil surface, which has historically been very difficult to do with available technology. The results also provide a long-term context for studies conducted in any particular period, and a basis for experimental manipulations of water to mimic dry, average, and wet years.

2. We recently completed a study of seasonality of soil water loss in shortgrass steppe. This study contributes to development of simple methods for estimating energy balance and evapotranspiration in areas with high proportions of bare soil. Microclimatic data commonly used to estimate water and energy balance were compared with weighing lysimeter data, which provided a direct estimate of water balance. Consistent relationships were found (1) between sensible heat flux and the mid-day difference between soil and air temperatures and (2) between total and net solar radiation. Evapotranspiration estimated from these relationships compared favorably with lysimeter data. This approach may provide a basis for estimating regional patterns of evapotranspiration from remotely sensed data and standard meteorological station data. It could also allow estimation of water balance in site specific research where weighing lysimeters, which are rare and expensive, are not present. Comparison of precipitation and lysimeter records also implied that dew formation may be common during the growing season; dew may be important to sustaining biological activity in surface soil between rains.

3). We have documented spatial patterns of soil water associated with small-scale disturbance. The spatial scale of soil water heterogeneity is consistent with the scale of gap dynamics. This result supports one of the basic assumptions of the individual-plant-based models that we are using in analyses of vegetation and ecosystem dynamics involved in recovery from disturbance and in analyses of regional controls of vegetation and ecosystem patterns. This study also demonstrated the feasibility of using time domain reflectometry to resolve soil water dynamics near the surface. (Hook and Lauenroth, in preparation)

4.) Soil water monitoring across topographic gradients and soil textures supports the idea that texture has an important influence on the spatial pattern of soil water, affecting both average water content at a point and occurrence of deep percolation. Runoff and redistribution of snow may also be important in some years, but texture is an important control in general.

5.) Large weighing lysimeter allows monitoring of inputs and evapotranspiration of water very accurately. Results of investigating drying cycles suggests that when the soil is wet to 75 cm it can take 50 days to deplete the stored water. By contrast when the soil is dry a small rainfall event (5 mm) can be completely lost in 3-5 days. We hope to analyze many of these data this year, through the efforts of visiting scientist Dr. Jai Singh from India.

List of recent products regarding water dynamics:

Hook, P. B. 1992. Individual-plant scale patterns of roots and soil resources in the shortgrass steppe. PhD Dissertation. Range Science Department, Colorado State University, Fort Collins. 186 p.

Hook, P.B., W.K. Lauenroth, and I.C. Burke. 1993. Spatial patterns of water, roots, and organic matter in shortgrass steppe: an individual-plant perspective on ecosystem dynamics. Bull. of Ecol. Soc. of Amer. 74(2) Program & Abstracts, 78th Annual ESA Meeting. Madison, WI.

Hook, P. B., W. K. Lauenroth, and I. C. Burke. Spatial patterns of plant cover and roots in a semiarid grassland: abundance of canopy openings, root gaps, and resource gaps. Submitted to J. Ecol.

Hook, P. B. and W. K. Lauenroth. Root system response of a perennial bunchgrass to neighbourhood-scale resource heterogeneity. Submitted to Functional Ecology.

Hook, P. B. and W. K. Lauenroth. Soil water dynamics in B. gracilis neighborhoods and gaps in shortgrass steppe. In Preparation.

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

e. Patterns and frequency of disturbance

Most of our disturbance work can be placed into two broad categories, small to intermediate-sized patchy disturbances, and large disturbances. We are using both experimental studies and simulation modeling to improve our understanding of the effects of disturbances on shortgrass systems.

Small, patchy disturbances

1.) We continue to monitor the response of shortgrass steppe ecosystems to small-scale disturbances. The small-scale disturbance work focuses on the responses of individual plants to disturbances at scales of 0.1 to <100 m^2, and uses gap dynamics concepts to explain the response of shortgrass plant communities to disturbance. Field studies of western harvester ant nest sites, small animal burrows, and artificially-created plots indicated that disturbance type and size were more important to plant recovery than time of year when the disturbance occurred. Additionally, B. gracilis plants have recovered on some of the disturbances, with long-term monitoring needed to determine the length of time required for this species to dominate on these areas. A large amount of variability has been observed between disturbed areas that is likely related to variability in vegetation surrounding each area.

2.) A field study of patches produced by the larvae of June beetles feeding on roots of B. gracilis plants was initiated in 1977 by the ARS. These 32 areas have been resampled five times (1978, 1979, 1980, 1982, 1990), and is currently part of the LTER. For some pastures, paired areas were found inside and outside exclosures; therefore we were able to analyze the effects of grazing on recovery. Average cover of B. gracilis recovered to 36% (grazed) and 51% (ungrazed) of undisturbed cover within five years. Rate of recovery of B. gracilis was not affected by grazing, although a more uniform mortality, and hence lower initial cover, occurred with grazing. Grazing was important in the recovery of other species.This work was recently presented at the Ecological Society of America meetings (Coffin et al. 1993) and is being synthesized into a manuscript (Coffin et al. in prep).

Large-scale disturbances

Our large scale disturbance work encompasses the long-term effects of grazing at m^2 to global scales and successional dynamics following cultivation, nutrient enrichment stresses, and arthropod outbreaks.

1.) Factors determining the differential effects of grazing on plant communities and soils around the world were assessed in a quantitative analysis of 300 data-sets of grazed/ungrazed comparisons from five continents. Sensitivities to grazing in terms of changes species composition, dominant species, and ANPP were more related to ecosystem (productivity, history of grazing, etc.) and environmental (precipitation, etc.) variables than to grazing variables (intensity, duration, etc.); where we graze is as important as how we graze. Although most effects on ANPP were negative, as many positive as negative effects of grazing on root biomass and soil nutrients were found. This study also suggests that shrublands may be grazed more intensely than grasslands, although the levels of grazing are perceived as similar; thus contributing to the conversion of grasslands to shrublands. This study was a quantitative follow-up to our theoretical consideration of the effects of grazing at a global scale (Milchunas and Lauenroth 1993).

2.) Our work on succession on nutrient enrichment and white-grub disturbances has allowed us to make comparisons of these treatments with the grazing treatments (Milchunas et al. 1990). A manuscript addressing the long-term trajectories (1971 to present) of these nutrient-enriched-communities has important implications for considerations of what can occur with 'subsidy-stress' effects of sulfur and nitrogen oxide pollutants and global warming (Milchunas and Lauenroth 1993c). We empirically show that inertia in plant community structure can produce lag-times in response, whereby deflection and chaotic trajectories can occur after the removal of the stress.

3.) In 1991, we initiated a new study to evaluate the long-term effects of grazing and recovery on shortgrass steppe ecosystem structure and function. As summarized above, we found in previous work that plant communities in shortgrass steppe do not appear to be significantly influenced by grazing, however, that soil organic matter is apparently higher in long-term exclosures than in grazed treatments. This raised interesting questions regarding the role of long-term exclosure in management interpretations. Specifically, we wanted to address the questions: what are the short- and long-term effects of grazing and of exclosure on ecosystem structure and function, and how do these effects interact with soil texture?

We have initiated a long-term study in which we have moved 50-year-old exclosure boundaries in 6 locations, across a soil textural gradient, to create 4 treatments: long term grazed, currently grazed; long term grazed, recently exclosed; long term exclosed, currently exclosed; and long term exclosed, currently grazed. We began a very large-scale sampling program in 1992 that addresses plant communities, individual plant survival, aboveground and belowground biomass and net primary production, soil organic matter dynamics (microbial biomass, in situ and potential mineralization rates), soil fauna, aboveground foliar nutrient concentrations, and soil erosion. We anticipate having a large number of immediate and long-term, integrative products from this study.

4). We conducted a study to evaluate the relationship between grazing by domestic livestock and the subsequent potential for loss of native communities to invasions by exotic species. Our results confirmed earlier observations that exotic species are more abundant in ungrazed compared to grazed treatments, but provides insight into the cause of this unusual phenomenon. We accomplished this by separating indirect, long-term effects of grazing from direct, short-term effects, and germination/microenvironment from survival/competition stages of demography. Microenvironmental conditions for germination in long-term ungrazed communities appear to be more important in establishing reproducing populations of exotics than differences between grazing treatments in the effects of levels of competition from existing plants on subsequent survival (Milchunas et al. 1993b).

5.) In 1990, we conducted a field study to evaluate the recovery of shortgrass steppe ecosystems on agricultural fields abandoned in the 1930's. Thirteen fields were selected to represent the precipitation and temperature gradients in northeastern Colorado, including one field at the CPER. Although the traditional view of shortgrass system recovery suggests that the dominant species, B. gracilis, fails to recover on large disturbances, our results found this species on all fields sampled 53 years after abandonment; B. gracilis dominated the cover on two of the fields. The fields were distinguished into four groups based on the spatial recovery pattern of B. gracilis across each field. Indices of recovery based on community measures indicated none of the fields had recovered to the unplowed state. A comparison of our results with two traditional models of succession for shortgrass communities indicated that few fields fit either model. The large variability in cover, density, and species composition found on these fields may be related to differences among fields in timing of precipitation and temperature, or historical events such as grazing intensity and length of cultivation (Coffin et al. in prep).

In addition, we found interesting recovery patterns of soil organic matter that appear to be linked with recovery of B. gracilis. These results are summarized above in the Soil Organic Matter core area. Manuscripts from this work are being submitted to Ecological Applications.

Plant community modeling

Our approach to modeling plant community dynamics has been to use a spatially-explicit individual-based gap dynamics simulation model (STEPPE) to evaluate the recovery of shortgrass communities after disturbances. The model is similar to the gap models used in forests, but is based on the importance of belowground processes in shortgrass communities rather than aboveground processes in forests. Because the results of this work have indicated the importance of processes associated with recruitment, especially for B. gracilis, our modeling efforts have included a focus on understanding controls on recruitment, and effects of weather and site conditions on recruitment, and effects of disturbance size, precipitation, and soil texture on recovery.

In our initial simulations that represented small disturbances, we found that availability of B. gracilis seeds is an important constraint on recovery (Coffin and Lauenroth 1990). Approximately 20 years were required for recovery by this species if its seeds are always present on a plot, and 40 to 60 years if seed availability (ie., production) is dependent upon precipitation. Subsequent simulations of intermediate-sized disturbances that included the spatially-explicit process of seed dispersal indicated that the distance from the source of seeds is an additional constraint as disturbance size increases (Coffin and Lauenroth 1989). Small disturbances recovered faster than large disturbances. Soil texture effects on seedling establishment were found to be more important than disturbance size in determining plant recovery (Coffin and Lauenroth in press). Disturbances on soils with high silt content had large B. gracilis biomass through time compared to soils with a low silt content.

We recently linked the STEPPE plant growth model with the SOILWAT model to allow feedbacks between plant processes and soil water processes to affect plant recovery and soil water dynamics. The models were linked using network functions under the UNIX operating system. By contrast to previous simulations of small and intermediate-sized disturbances (0.1 to 49 m^2), these simulations represented large-scale disturbances, and in particular plant recovery on abandoned agricultural fields. Simulated fields on soils with the largest silt and smallest clay contents had the fastest recovery of B. gracilis biomass through time compared to soils with large silt and clay contents. Old fields on silt loams soils were the only disturbances where B. gracilis recovered to the end of the 42 m transect by year 200. A comparison of simulated results with field data at the same site indicate that B. gracilis can recover much faster than previously estimated (Coffin et al. 1993).

List of recent products regarding disturbance:

Burke, I. C., W. K. Lauenroth, and D. P. Coffin. Response of a semiarid grassland to large-scale disturbance: Recovery of soil organic matter and nutrient supply capacity. Submitted to Ecological Applications.

Coffin, D.P. and W.K. Lauenroth. 1993. Successional dynamics of a semiarid grassland: Effects of soil texture and disturbance size. Vegetatio (in press).

Coffin, D. P., W. K. Lauenroth, and I. C. Burke. 1993. Spatial dynamics in recovery of shortgrass steppe ecosystems. pp75-107 IN R. H. Gardner,ed. Some mathematical questions in biology: Predicting spatial effects in ecological systems. American Mathematical Society, Providence, RI.

Coffin, D. P., W. K. Lauenroth, and I. C. Burke. Response of a semiarid grassland to large-scale disturbance: Recovery of vegetation. To be submitted to Ecological Applications.

Coffin, D.P., W.K. Lauenroth, and W.A. Laycock. 1993. Patchy disturbances in a semiarid grassland: Recovery of vegetation. Bull of Ecol. Soc. of Amer. 74:2.

Fahrig, L.D., D.P. Coffin, W.K. Lauenroth, and H.H. Shugart. The advantage of long-distance clonal spreading in highly disturbed habitats. Evolutionary Ecology (in press).

Ihori, T., and I. C. Burke. Effects of disturbance and recovery on small-scale heterogeneity of in situ N mineralization in semiarid grassland soils. Submitted to Plant and Soil.

Ihori, T., I. C. Burke, W. K. Lauenroth, and D. P. Coffin. Effects of cultivation and recovery on soil organic matter in northeastern Colorado. Submitted to Soil Science Society of America Journal.

Lauenroth, W.K. and D.P. Coffin. 1992. Belowground processes and the recovery of semiarid grasslands from disturbance. pp 131-150 In Vol 2: Ecosystem analysis and synthesis (ed) M.K. Wali, SPB Academic Publ, The Hague, The Netherlands.

Lauenroth, W.K., D.G. Milchunas, J.L. Dodd, R.H. Hart, R.K. Heitschmidt, and L.R. Rittenhouse. 1993. Grazing in the Great Plains of the United States. In M. Vavra and W.A. Laycock (eds) Ecological Implications of Livestock Herbivory in the West.

Society for Range Management (in press).

Milchunas, D.G. and W.K. Lauenroth. 1993. Momentum in plant community structure: deflection after cessation of stress. Bull. of Ecol. Soc. of Amer. 74:2.

Milchunas, D. G., W. K. Lauenroth, and P. L. Chapman. 1993. Plant competition, abiotic, and long- and short-term effects of large herbivores on demography of opportunistic species in a semiarid grassland. Oecologia 92:520-531.

Milchunas, D. G., A. S. Varnamkhasti, W. K. Lauenroth, and H Goetz. 1993. Interactions between grazing history, defoliation, and precipitation: 2) plant nitrogen and digestibility. Oecologia (submitted).

Parton, W.J., W.E. Reibsame, and C.V. Cole. 1992. Social and environmental controls on land use of temperate grasslands and croplands. Bull. of Ecol. Soc. of Amer. 73:2.

2. SYNTHESIS ACTIVITIES

a). Cross-site integration and synthesis

We are involved in a number of important cross-site activities. Several of these are long-term and ongoing.

i). Global change analysis for LTER sites. This is a modeling project led by Bill Parton et al, funded by an LTER supplemental grant.

2). Analysis of population-ecosystem interactions in grasslands. Mary Ann Vinton (graduate student) and I. Burke are conducting an analysis of species-ecosystem interactions across a moisture gradient, including the CPER, Hays Kansas, and the Konza LTER site.

3) Analysis of plant community - ecosystem dynamics in semiarid and arid grasslands. Debra Coffin is leading a project funded by a supplemental LTER grant to address these interactions across a gradient from the Jornada dry grassland, to the Sevilleta semiarid grassland, to the CPER.

Here we present a list of published and in press papers that are examples of the activities of CPER-LTER scientists in cross-site integration and syntheses. The citations for these papers can be found in the CPER-LTER publication list.

Burke and Lauenroth 1993 - Analysis of the regional applicability of results from the CPER-LTER project using GIS.

Lauenroth and Sala 1992 - Analysis of a long-term data set of aboveground net primary production for the CPER. The key intersite result came from comparing a regression model of production through time with a model for the grassland region. This revealed an important problem with space-for-time substitutions.

Lauenroth and Milchunas 1992 - Synthesis of available research for the shortgrass steppe region of North America.

Lauenroth et al. 1993 - Presentation of a modeling framework and a plan to evaluate interactions between ecosystem structure and processes across a range of sites from forests to deserts.

Lauenroth et al. 1993 - Analysis and synthesis of effects of domestic livestock grazing on ecosystems of the Great Plains of the U. S.

Milchunas and Lauenroth 1993 - Empirically-based synthesis of ecosystems world-wide to grazing by large generalist herbivores.

b. Simulation modeling

Simulation modeling is an activity that we consider to be an indispensable part of any ecological investigation. Our work in this area has concentrated on models of water dynamics (SOILWAT; Parton 1978), plant community structure (STEPPE; Coffin and Lauenroth 1990), and production and turnover of soil organic matter (CENTURY;Parton et al. 1988). We have operational simulation models for each of these topics that we routinely use to aid us in our formulation of questions and hypotheses and in interpretation of field and laboratory data.

We are using the multi-layer, daily timestep soilwater model (SOILWAT) to address questions concerning long-term patterns in soilwater dynamics (Sala et al. 1992) (described under the Water Dynamics Core Topic), and to evaluate the importance of soilwater dynamics of different soil textures to the establishment of seedlings of Bouteloua gracilis (Lauenroth et al. submitted) (described under the Trophic Structure Core Topic). We are using the individual plant-based gap dynamics simulation model (STEPPE) to evaluate the recovery of shortgrass communities after disturbances. We are evaluating the importance of disturbance size and soil texture to plant recovery on small and intermediate-sized disturbances (Coffin and Lauenroth in press). We recently linked the STEPPE and SOILWAT models to allow feedbacks between plant processes and soil water processes to affect plant recovery and soil water dynamics. Results from these simulations of large-scale disturbed areas (ie., abandoned agricultural fields) indicate that B. gracilis can recover much faster than previously estimated from data using a chronosequence of old fields (Coffin et al.

1993) (described under Disturbance Core Topic). Recently we compared results from the STEPPE model with a similar model used in forests (ZELIG) to evaluate the implications of similarity and differences in life history traits between grasses and trees to the dynamics of the two systems (Coffin and Urban 1993). We are using CENTURY to evaluate climate change scenarios for the CPER as well as for the other terrestrial LTER sites.

Coffin, D.P., W.K. Lauenroth, I.C. Burke. 1993. Spatial dynamics in recovery of shortgrass steppe ecosystems. In R. Gardner, ed. Theoretical approaches to predicting spatial effects in ecological systems (in press).

Coffin, D.P. and D.L. Urban. 1993. Implications of natural history traits to system-level dynamics: Comparisons of a grassland and a forest. Ecol. Mod. 67:147-178.

Lauenroth, W.K., D.L. Urban, D.P. Coffin, W.J. Parton, H.H. Shugart, T.B. Kirchner, and T.M. Smith. 1993. Modeling vegetation structure-ecosystem process interactions across sites and ecosystems. Ecol. Mod. 67:49-80.

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

c. Regional Analysis

A question that we consider to be integral to our LTER responsibilities is: To what portion of the surrounding area are our LTER results applicable (Burke and Lauenroth 1993)? The application of our results to both scientific and management questions depends upon the answer to that question. The availability of powerful spatial analysis tools (Geographic Information Systems) and our work on simulation models made the combination of these two technologies the logical way to address the question. Our work on this topic was begun with an LTER supplemental grant in 1988 and ended in 1990 when the LTER proposal review panel mandated that we focus all of our LTER efforts on the Central Plains Experimental Range.

Burke, I. C. and W. K. Lauenroth. 1993. What do LTER results mean? Extrapolating from site to region and decade to century. Ecological Modelling 67:49-80..

Burke, I.C. and W.K. Lauenroth. 1992. Regional analysis of temperate grasslands. SCOPE Workshop. Upsala, Sweden September 1992.

Burke, I.C., W.K. Lauenroth, W.J. Parton, and C.V. Cole. 1992. Interactions of landuse and ecosystem structure and functions: A case study in the Great Plains. Integrated Regional Modeling Workshop. Institute of Ecosystems Studies October 1992.

Burke, I. C. 1993. Regional assessment of landuse in the central Great Plains. Plenary address to the 8th annual US Landscape Ecology Symposium, Oak Ridge, TN. March 1993.

Fan, W., W.K. Lauenroth, D.P. Coffin, and I.C. Burke. 1993. Regional analysis of the relationships between geographic distributions of plant species and environmental factors in the shortgrass steppe. Bull. of Ecol. Soc. of Amer. 74:2.

3. CURRENT INTERNATIONAL COLLABORATIONS

The major current international collaborative efforts of the CPER-LTER project are with Dr. Osvaldo Sala at the University of Buenos Aires in Argentina and a group at the Institute for Soil Fertility in The Netherlands. We have lessor but potentially important involvement with the CERN program of the Peoples Republic of China.

University of Buenos Aires

Our collaborative work with Dr. Sala has two important dimensions. The first is focused on comparisons between his research site at Rio Mayo in Chubut province in the Patagonian region of Argentina (45° 41' S, 70° 16' W) and the CPER. This work has been ongoing for approximately 10 years and has been supported by the CPER-LTER project as well as two grants from the International Division at NSF. This work has involved Dr. Sala, Professor Alberto Soriano, and a number of their graduate students. Two of the students who earned Masters degrees at the University of Buenos Aires working at Rio Mayo are currently working on doctoral degrees with the CPER-LTER project at Colorado State University.

The second dimension has to do with the work Dr. Sala has that is directly related to the objectives of the CPER-LTER project. Dr. Sala has visited Colorado State University many times in the past 10 years staying from 1 month to 1.5 years. During those visits he has worked with quite a large group of CPER scientists.

Institute for Soil Fertility

In addition, the belowground food web research that was initiated at the CPER in part has led to a long-term collaboration with the Institute for Soil Fertility, The Netherlands. The Dutch have long been interested in soil ecology as a large portion of their country is managed as pasturelands and is under cultivation. In many respects, our European colleagues have shown a greater appreciation for the importance of soil biota on soil processes. The work conducted at the CPER has been unique in that it has studied soil biota from a systems perspective. The approach and the models developed at the CPER have been adopted by the Dutch in their research. These interactions have been led in part by Dr. E. T. Elliott and C. V. Cole, who are not formally investigators on the LTER but who are close associates on other projects, and by Dr. John Moore, a new Co-Investigator on our project.

CERN (Chinese Ecological Research Network)

Our collaborative efforts with CERN have been closely related to the efforts of the network to establish a relationship with the Chinese and help them in their efforts to get an LTER-like program started in China. We were one of several sites that the Chinese delegation visited in 1991 and two CPER scientists (Dr. D.P. Coffin and Dr. T.B. Kirchner) visited China with separate U.S delegations. Our interactions with the CERN leadership have resulted in important changes in their plans for including simulation modeling in their research programs. Our future involvement with CERN is dependent upon the Chinese response to our proposal to provide training in simulation modeling of ecological systems. If it is accepted we would work with Chinese visiting scientists at Colorado State University.

We have recently been funded by an LTER supplemental award to bring Dr. Jai Singh from India to work here for a half-year. Dr. Singh is a grassland ecologist who has worked with us previously during the US International Biological Program and we plan to work with him on an analysis of our long-term soil water data.

4. INTERACTIONS WITH OTHER SCIENTISTS AND RESEARCH PROJECTS

The CPER is a focal point for a large amount of ecological research conducted by scientists in Fort Collins. We would like to be careful in accepting credit for this. The site is an ARS Experiment Station, and was an IBP site, in addition to being an LTER site. Thus, there are a number of compelling reasons for working at the CPER, including not only LTER research activities, but also a long historical database associated with the ARS and the IBP, and the long-term grazing management provided by the ARS. However, the LTER project does provide kinds of research and attractiveness to the site that would not be present if it were simply an ARS research facility. Furthermore, if it were not for the LTER the IBP database and a portion of the ARS database would not be available to current researchers.

The following is a list of non-ARS and non-LTER research projects conducted or on-going at the CPER during the present:

Bonham, C. D. Forage production and spatial patterns of species on rangelands. Colorado State Experiment Station - (CSU)

Bonham, C. D. Development of strategies for stabilization of grassland plowouts in the central Great Plains. Colorado State Experiment Station - (CSU)

Burke, I. C., W. K. Lauenroth, D. P. Coffin, and W. J. Parton. Regional analysis of ecosystem structure and function in the central grasslands of the United States. NSF $427,108.

Bushra, I. and J. K. Detling. Some ecological implications of foraging strategies in buffalograss. Pakistan $21,000

Delany, T. Atmospheric gas analysis. NSF, NCAR - (U. Colo.)

Elliott, E. T., E. A. Paul, I. C. Burke, K. H. Paustain. Agroecosystems carbon pools and dynamics. EPA - (CSU, Michigan State Univ.) $900,000.

Elliott, E. T., W. J. Parton, C. V. Cole, D. S. Schimel, H. W. Hunt, I. C. Burke, G. A. Peterson, D. G. Westfall. Organic C, N, S and P formations and loss from Great Plains Agroecosystems. NSF - (CSU) $1,617,780.

Fox, D. Eddy correlation estimation of dry deposition fluxes of ozone, NO_2, and NO_x. Rocky Mountain Forest and Range Experiment Station

Gibson, J. National Atmospheric Deposition Program. USGS, USDA-CSRS, EPA, Colorado Experiment Station - (CSU) $7,000/yr for CPER site.

Goetz, H., A. Menweylet, and J. K. Detling. Defoliation effects on western wheatgrass (Pascopyorum smithii plants in long-term protected and long-term grazed pastures. Colorado State Experiment Station (CSU) $60,000

Holling, C. S. and J. Sendzimir. Scaling of foraging areas of mammals and vegetation patterns. U. of Florida

Hunt, H. W., E. T. Elliott, J. K. Detling, T. G. F. Kittel, D. E. Walter, and D. W. Freckman. Response of a temperate grassland ecosystem to climate change: importance of biotic interactions and feedbacks. NSF - (CSU) $2,000,000.

Ibarra-Gil, H. and J.K. Detling. Plant responses to defoliation and competition at two landscape positions in a shortgrass steppe. CSU, CONACYT (Mexico) $70,000

E.F. Kelly, A.J. Busacca. The Geologic and Pedologic Record of Climate and Vegetation in Pleistocene Palouse Loess, Pacific Northwestern U.S. NSF, Division of Earth Sciences. (CSU, Washington State University) $116,016.

E. F. Kelly, R.G. Amundson, M. Grabel, L. Tieszen. The Relationship of Climate to the Stable Isotopic Composition of Hackberry (Celtis) Endocarps: A Potential Means of Paleoenvionmental Reconstruction in the Great Plains. NSF, Division of Earth Sciences. (CSU, UC Berkeley, Black Hills State, Augustana College) $26,686.

E.F. Kelly, C.G. Olson. The Soil Survey and Pedologic/Geomorphic studies of the Central Plains Experimental Range". United States Department of Agriculture, "(CSU, NSSC, USDA-SCS) $20,000.

E.F. Kelly. The Influence of Climate on the Isotopic Composition of Soil Organic Matter". Colorado State University Experiment Station. $4,000.

E. F. Kelly. A Chronosequential Evaluation of Carbon Fixation in Great Plains Soils. United States Geological Survey, $3,000.

E. F. Kelly. The Paleoecology of the Central Plains Experimental Range, Colorado. Faculty Research Grants, Colorado State University, $4,007.

Lauenroth, W. K. and O. E. Sala. Grass/shrub interactions in two temperate semiarid regions. NSF - (CSU, Univ. Buenos Aires) $50,885.

Lauenroth, W. K., T. B. Kirchner, O. E. Sala, and A. Soriano. Convergence in resource partitioning among plant growth forms in two semiarid regions. NSF - (CSU, Univ. Buenos Aires) $19,970.

McCaffery, B. J. Population ecology and mating system of the mountain plover. (Cornell Univ.)

McEwen, L. and J. Logan. Assessment of direct and indirect effects of xenobiotic chemicals on small mammal populations. EPA - (CSU) $123,290.

Monson, R. K. Environmental factors regulating seasonal growth, photosynthesis and resource utilization in shortgrass prairie. (Univ. Colorado)

Moore, J., H. W. Hunt, and D. W. Valentine. Experimental tests of microclimate substrate quality and soil properties on decomposer specificity in adjacent lodgepole pine and mountain meadow. NSF - (CSU, U. Northern Colorado) $230,000.

Morgan, J. A., W. Knight, and H. W. Hunt. Responses of rangeland grasses to atmospheric CO_2 and water. USDA-NRICG $210,000.

Mosier, A., D. S. Ojima, D. W. Valentine, W. J. Parton, D. S. Schimel, C. W. Rice. Trace gas production from rangelands.

Redente, E. F. and L. A. Hoffmann. Small mammal granivory and herbivory: a trophic constraint on the establishment of native grasses. Colorado Agricultural Experiment Station - (CSU) $120,000.

Rittenhouse, L. R. Feeding behavior of free-grazing cattle. NORAD and Colorado State Experiment Station - (CSU) $3000.

Schimel, D. S., I. C. Burke, A. Mosier, J. Pastor, C. Johnston, R. Hoffer, and W. J. Parton. Regional modeling of trace gas production in grassland and boreal ecosystems. NSF - (CSU, U. Minnesota) $1,187,791.

Schimel, D. S. and C. Wessman. Using multi-sensor data to model factors limiting carbon balance in global arid and semiarid lands. NASA - (CSU, Univ. Colorado)

Schimel, D. S., W. J. Parton, T. G. F. Kittel. Land surface-climatology interactions. NASA - (CSU)

Shugart, H. H. and W. K. Lauenroth. Coupling ecosystem processes and vegetation structure across environmental gradients. NSF - (Univ. Virginia, CSU) $1,219,621

St John, T. V. Fraction of net primary production attributable to mycorrhizal fungi in a shortgrass steppe ecosystem. NSF - (CSU)

Trlica, J. Structural and functional differences between a simple and diverse grassland ecosystem in carbon and nitrogen allocation and utilization. NSF - (CSU).

Turner, S. J., and J. Trlica. Coexistence and competition between two grasses on the shortgrass steppe ecosystem. Colorado State Experiment Station - (CSU)

Weins, J. and B. Milne. Boundary dynamics approach to studying landscapes. NSF - (CSU, Univ. New Mexico)

Williams, G. J. Photosynthesis and transpiration of shortgrass steppe plants. Washington State Agricultural Exp. Station

5. DATA MANAGEMENT

The primary goal of data management is to provide long-term storage and maintenance of the LTER data. The design of our archival procedures, data base, and data base access system are all oriented toward achieving this goal. The second goal for data management is to provide assistance in the analysis of the data and the use of the data in modeling activities. The data management staff currently includes Tom Kirchner, the data manager, and Steve Chaffee, the programmer for the LTER project.

Data management starts before data collection is ever started at the site. The data management staff works with investigators to develop data entry forms and procedures. These forms are designed to ensure that all necessary auxiliary data are recorded, that data can be accurately transcribed from the forms, and if possible that data can be stored in the original format. The staff also helps investigators prepare additional documentation for the data sets.

Data collected using field forms is filed with the programming staff on campus. About every six months the data forms are sent to be keypunched by a professional data entry service. These data are verified as part of the data entry process. Data returned from keypunching are in turn reviewed by the investigators before being entered into the database. The original field forms are then filed and periodically are microfilmed and archived.

Some data from the site are recorded on cassette tapes using a CR21X data logger(Campbell Scientific Instruments Inc.). These data are transferred at the field site to floppy diskettes which are then filed with the programming staff. The data are then transferred to a Sun workstation for processing. The data are initially processed by a data "filter" that verifies that the data values fall within reasonable ranges. Where errors occur in the data stream the filter reports the errors and replaces the data with missing value codes.

The LTER database is a collection of ASCII files that are maintained on Sun Microsystem workstations housed within the Natural Resources Building at Colorado State University. These data are the primary data for the project and consist of the original verified field observations. The LTER database is backed up to 8-mm cassettes as part of the standard backup procedure for the local network. In addition special backup tapes are made about every six months. One copy of the data is retained by the data manager at his home, and one copy is kept by the PI. Secondary databases, created using database management systems such as Paradox, are derived from the primary database as needed for analysis by the investigators. Although these secondary databases are the responsibility of the investigators, the LTER data management staff will provide assistance with managing the secondary database systems as necessary and when time permits. We have created filters and formatters to transfer data to Lotus 1-2-3 and other applications.

The data of the primary database are stored as ASCII files to insure that the files can be read decades from now. Two types of files are maintained. The first set of files contain the field data from experiments or monitoring studies conducted at the Central Plains Experimental Range by the LTER project and other previous and contemporary research projects. These data include observations collected prior to the start of the LTER project, primarily from the International Biological Program's Pawnee site. The second file type is a description file that provides a description of the format of the data, the name of the investigator responsible for the data, methods used for collecting the data, problems encountered with the collection of the data, and other pertinent information. Such documentation of a data set is often called metadata. The documentation of the data is absolutely essential if the data are to be used in the future. Many of the data sets collected under the IBP do not yet have adequate data description files. We are adding these descriptions to the database as time permits.

The investigators associated with the LTER project have offices in many different buildings across the campus. In addition, the LTER database is used by scientists across the nation. We have developed tools for accessing the data in the LTER database from anywhere that has access to the internet network from a UNIX workstation or a PC. The system is based on a distributed client-server approach using Remote Procedure Call functions to access the data and metadata files. The system is designed so that the server, running on one of the LTER workstations, receives a request for data, locates the data, and transfers a copy of it back to the client. The client never has direct access to the data files. An application program called ltermenu provides an interactive interface to the database. Ltermenu provides a menu of data sets that can be accessed and downloaded. Ltermenu also can display the data description for any data set, can list the data, can extract a subset of the data fields, and can plot the data.

LTER data management also includes the maintenance of a bibliographic data base for publications related to the LTER project and the CPER site. The list of publications is updated annually, printed and distributed. The bibliography is also maintained on the network. Recently we have begun to investigate the feasibility of providing bidirectional links between entries in the bibliographic database and the metadata files for the data used in the reference. Using FrameMaker as a display engine for the bibliography allows us to use the links to create a hypertext system. This system enables an investigator to easily view the data description or data associated with a reference, or to view the references associated with a data set. This methodology looks practical, but will require additional work before it is fully functional.

We are also involved with the enhancement of intersite activities related to data management. The Intersite Climate Database project was put together by John Gorentz at Kellogg Biological Station to develop prototypes for methods to exchange data between LTER and other sites. Gorentz's approach centered on using e-mail as the transport mechanism for exchanging data and was restricted to Structured Query Language (SQL) database systems. John Briggs (Konza Prairie), Barbara Benson (North Temperate Lakes), and Mark Klingensmith (Bonanza Creek) participated in the project by assembling their sites climatic data into an SQL database. A second thrust of the project was to put together a library of Interprocess Communication (IPC) functions to implement file transfer procedures directly using Remote Procedure Call (RPC) methods. These functions were designed to facilitate the construction of distributed client and server applications. The applications could be written in either FORTRAN or C. Tom Kirchner (Central Plains Experimental Range) took responsibility for this part of the project.

The IPC library has been completed and is now in the last stages of being documented. Ltermenu, which makes use of the IPC library, has been ported to X-Windows under UNIX and to the PC under DOS. A server designed to access the Konza Prairie SQL climate database is now being developed. The server will accept a request for a data set (table) from ltermenu or similar applications, retrieve the data, generate a metadata file to describe the format of the data, then send the metadata file and data to the client application.

The LTER data managers agreed at the July, 1993 Data Manager's meeting to pursue methods to facilitate the exchange of data between the sites. The strategy to be employed is to use a common metadata format to describe the data being transferred. Tools will be developed to convert from the metadata format employed at each sites to the common format. Additional tools such as ltermenu will be developed to efficiently access and reformat the data. The common format to be used is the extensible metadata format developed by Tom Kirchner for the CPER database system.

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