PROJECT PLAN
205 RANGELAND, PASTURE AND FORAGES
NP-205 (70%)
NP-304 (30%)
September-October, 2003

Old CRIS Project Number
5409-12630-001-00D

Research Management Unit
5409-25-Rangeland Resources Research Unit

Location
Cheyenne, Wyoming

Old Title
"Plant and Animal Responses to Environment and Management"

New Title
"Rangeland Ecosystems: Characterization, Management and Monitoring"

Investigators
D. Terrance Booth.. 80%
Dana M. Blumenthal 80%
Justin D. Derner, Lead Scientist 60%
Jack A. Morgan 30%
Jean D. Reeder... 50%
Gerald E. Schuman... 30%

Scientific Staff Years
3.3

Planned Duration
42 months

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Pre-Peer Review

Justin D. Derner
5409-12630-001-00D
Rangeland Ecosystems: Characterization, Management and Monitoring

This project plan was found to meet the peer review criteria, to be in compliance with the Project Plan Instructions and Format, and demonstrate how the research team will conduct research in a manner appropriate for this area of research. The funds committed toward this project are sufficient to support the planned research.

Jack A. Morgan___________________________________ July 24, 2003________________
Research Leader Date

This project plan was prepared by a qualified research team and demonstrates the research team's best effort towards achieving the assigned research objectives.

____ ____________________
Center, Institute, or Lab Director Date

This project plan is relevant to the Agricultural Research Service's National Program 205 Action Plan and was prepared in accordance with the outlined objectives, experimental approach, and project duration previously agreed to by the National Program Team and research team.

____ ____________________
National Program Leader Date

This project plan was prepared by a qualified research team and demonstrates the research team's best effort towards achieving the assigned research objectives. All internal review and approval requirements have been met. To validate the plan's readiness for implementation and gain recommendations for improvement, the project plan is now available for peer review.

____ ____________________
Area Director Date

These officials have not performed a scientific merit peer review. Their statements do not necessarily require expertise in the specific subjects associated with this research. The approval to implement this project plan cannot be made without scientific peer review coordinated by the Office of Scientific Quality Review, ARS, USDA.

Re-do this coversheet if the project plan requires a second peer review.

For labs that have a 3-tier organization structure (vs. the 4-tier organization that is implied on the signature page), you may combine the first and second signature block. If your lab uses a different title for the Research Leader or Center Director, you may edit the title lines accordingly.

Project Summary

This effort will increase basic ecological knowledge needed to manage and monitor semi-arid rangeland ecosystems (shortgrass steppe, northern mixed-grass prairie and sagebrush steppe). Because these rangeland ecosystems often exhibit nonlinear dynamics, we will use the state-and-transition model theory as a conceptual underpinning to study plant community attributes and key ecological processes involving C, N and water. Our first objective is to increase the accuracy and utility of state-and-transition models by testing their ability to classify and predict vegetation change, and learn how grazing (intensity and season of use), plant resources (N and water), and exclusion of plant enemies (insects and pathogens) influence vegetation change in northern mixed-grass prairie and shortgrass steppe. C, N and water processes will be studied to provide insight into potential mechanisms that govern changes between states of vegetation and may be used in a predictive manner to clarify how and when transitions occur. Enemy exclusion and resource manipulation experiments will target mechanisms underlying the increase of invasive weeds in these systems. Our second objective is to develop very large-scale aerial (VLSA) photography and ground photography methods to accurately monitor bare ground, plant cover and plant communities in sagebrush and shortgrass steppe and northern mixed-grass prairie. Experiments will address the utility of VLSA to assess landscape scale patterns of weed invasions, and to determine the correlation in changes in bare ground and plant cover from VLSA photography to net ecosystem production, and water and energy fluxes.

Objectives
The management of complex native rangeland ecosystems requires both a fundamental understanding and characterization of ecosystem dynamics (Objective 1) and tools to allow managers to monitor those dynamics (Objective 2).

<u>Objective 1</u>: Increase the accuracy and utility of state-and-transition models by testing their ability to classify and predict vegetation change, and learn how grazing (intensity and season of use), plant resources (N and water), and exclusion of plant enemies (insects and pathogens) influence vegetation change in northern mixed-grass prairie and shortgrass steppe.

<u>Objective 2</u>: Develop very large-scale aerial (VLSA) photography and ground photography methods to accurately monitor bare ground, plant cover and plant communities in sagebrush and shortgrass steppe and northern mixed-grass prairie.

Need for Research
Description of Problems to be Solved:

1) **Problem**: Reliable methods for characterizing vegetation states and transitions between vegetation states are lacking. **Gap**: State-and-transition models are being developed by the Natural Resource Conservation Service (NRCS), but the operational utility of these models has yet to be tested.

2) **Problem**: Despite the need to manage rangelands to achieve desired vegetation states, experimental data and the underlying theory required to develop such management practices are lacking. **Gap**: Previous rangeland grazing research has focused primarily on animal performance and efficiency of forage utilization, but these efforts have not addressed the influence of season of use or overgrazing from the perspective of intentionally changing vegetation states. Further, grazing research has largely neglected C, N and water processes associated with vegetation change.

3) **Problem**: The replacement of desired vegetation by invasive weeds [e.g., cheatgrass (*Bromus tectorum*) and dalmatian toadflax (*Linaria dalmatica*) in northern mixed-grass prairie] is degrading rangeland ecosystems. **Gap**: Although many factors contribute to invasion, insufficient attention has been given to understanding the relative importance of natural enemies and resource availability. This knowledge is critical for scientists and managers in prioritizing weed management strategies.

4) **Problem**: We do not yet have accurate rangeland monitoring tools. **Gap**: Current monitoring techniques are not rapid, reliable and repeatable over extensive land areas (e.g., allotments, watersheds).

Relevance to ARS National Program Action Plan: This project addresses goals outlined in the Rangeland, Pasture and Forages Action Plan relating to grazing impacts on ecosystems, invasive and noxious weeds, and monitoring and assessment technologies. This project has elements that address parts of other national programs including 1) Crop Protection & Quarantine (weed biology and ecology; plant, pest and natural enemy interactions and ecology), 2) Soil Resource Management (soil conservation, soil water) and 3) Global Change (carbon cycle and storage and agricultural ecosystem impacts).

Potential Benefits: Land managers, scientists, governmental entities and the public will benefit from this project. Land managers will be provided experimental results demonstrating how changes in season of use (early/late summer grazing vs. traditional season-long grazing) and intensity (overgrazing vs. traditional moderate) change the diversity and abundance of desirable species in northern mixed-grass prairie and shortgrass steppe. Scientists will be provided long-term data sets from grazing experiments that can be used for modeling efforts. Incorporating both natural enemies and resource availability within the same weed experiments will provide land managers and scientists an initial assessment of which factors are most important to rangeland weed invasion. Governmental entities [principally the NRCS and Bureau of Land Management (BLM)] will benefit from tests of state-and-transition models in semi-arid grasslands to provide confirmation and/or re-formulation of management models. Land managers, scientists and governmental entities will benefit from our continuing integration of VLSA photography and ground photography with computer image measurement techniques to assess bare ground, plant cover and plant communities. The public will benefit through sustainable management of resources that support rural economies, provide ecosystem services and conserve biological diversity.

Anticipated Products: Products will include 1) improved state-and-transition models that can be utilized by the NRCS, BLM, Forest Service, and other public and private rangeland managers, 2) identification of management practices that maintain, or initiate a transition to, a desired vegetation state, and 3) monitoring techniques that accurately assess rangelands and predict effectiveness of management practices. Product delivery will include refereed papers, popular press articles, oral and poster presentations at public and scientific meetings, and direct technology transfer to agencies in cooperative projects.

Customers: Grazing strategies will be used by land managers in the Northern Great Plains states. Improved state-and-transition models will be used by the NRCS. Monitoring techniques will be used by federal, state and private land management entities. Basic and applied ecological information on ecosystem dynamics of semi-arid rangeland ecosystems will be used by university, federal and private research organizations.

CSREES-CRIS Search: This project is ARS's only rangeland project that has field sites in both the northern mixed-grass prairie and the shortgrass steppe. ARS has rangeland projects in northern mixed-grass prairie at Mandan, ND, which addresses integrated forage, crop and livestock systems and at Miles City, MT, which also has Sagebrush grasslands, emphasizing low risk management strategies for sustaining range beef cattle production systems. ARS, however, does not have any other rangeland projects in the shortgrass steppe. Closely related ARS rangeland projects in other ecosystems include the ecology and management of Great Basin rangelands at Burns, OR, of southern mixed grass prairie at Woodward, OK, and of arid/desert rangelands at Las Cruces, NM. Additionally, the ARS rangeland project at Las Cruces is working on state-and-transition models for the Chihuahuan desert. Weed management/control projects are ongoing in the northern mixed-grass prairie at Sidney, MT, and in Great Basin rangelands at Burns, OR, and Reno, NV. Rangeland assessment projects addressing monitoring indicators are located at Las Cruces, NM and Boise, ID. Remote sensing, GPS and GIS have been integrated for natural resource management at Weslaco, TX, and remote sensing has been coupled with model assessment for range management at Tucson, AZ. This research project will involve cooperative research funded Specific Cooperative Agreements with the University of Wyoming and Colorado State University.

National Collaboration

This project is coordinated and closely connected with the Unit's other research project in National Program 204 (Global Change), which addresses semi-arid rangeland responses to management and global change. Current and planned experiments in the Unit's Global Change project are evaluating 1) the effects of increased atmospheric carbon dioxide (CO_2)

concentration and altered winter and summer precipitation amounts on ecological processes and vegetation change in northern mixed-grass prairie, 2) interseeding of legumes and shrubs to initiate transitions to enhance C storage and reduce greenhouse gas emissions in northern mixed-grass prairie and sagebrush steppe, and 3) the influence of land management practices on emissions of trace greenhouse gases. Emphases on soil C and N cycles, and greenhouse gases in response to global change and management dovetails with this project. We will collaborate with ARS National Program 205 projects at Dubois, ID, and Beltsville, MD, on evaluating the effectiveness of VLSA photography and ground photography to accurately monitor bare ground, plant cover and plant communities. Additionally, the BLM, The Nature Conservancy and the University of Wyoming will collaborate with the evaluation phase of this monitoring tool. Cooperative research on grazing projects in the shortgrass prairie will be conducted with Colorado State University and the Shortgrass Steppe Long-Term Ecological Research (SGS-LTER). Also, this project is affiliated with the oldest livestock cooperative in the nation, the Crow Valley Livestock Cooperative, Inc., involving grazing studies in the shortgrass steppe. Cooperative research on grazing projects in the northern mixed-grass prairie will be conducted with the University of Wyoming, the 8A Hay and Cattle Company and the R Bar H Ranch. Efforts may be initiated to establish collaborative grazing and invasive weed research with ARS National Program 205 project at Miles City, MT. Limited simulation modeling efforts are coordinated with the ARS Systems Unit in Ft. Collins, CO.

Approach and Research Procedures
Scientific Background: Literature Relevant to Objective 1.

State-and-transition models: Approximately 50% of the earth's terrestrial surface is classified as rangeland (Heady 1975). Rangeland ecosystems can be characterized by ecoregions (Bailey 1998), environmental gradients (i.e., arid, semi-arid and temperate rangelands), dominant vegetation (i.e., grassland, savanna, shrubland), photosynthetic pathway [C_4 (warm-season plants) or C_3 (cool-season plants) Teeri and Stowe 1976, Hattersley 1983, Tieszen et al. 1997], potential natural vegetation (Kuchler 1964), plant functional types (Paruelo and Laurenroth 1996), evolutionary history of large herbivore grazing and moisture gradients (Milchunas et al. 1988), physical structure (e.g., tall-, mid- and shortgrass prairies), structure and function (Sims and Singh 1978, Sims et al. 1978, Laurenroth et al. 1999), precipitation (e.g., mesic and xeric environments), "health" (i.e., healthy, at-risk, unhealthy, NRC 1994, Pyke et al. 2002) and condition (excellent, good, fair, poor, Dyksterhuis 1949). Yet, characterization of rangelands using these approaches is often general or inherently vague, and most often not done on a scale that is applicable to individual land managers. In contrast, the ongoing effort by the NRCS to complete conceptual state-and-transition models for ecological site descriptions (ESDs, *sensu* range sites) in major land resource areas (MLRAs) is directed towards the expressed purpose of providing land managers with decision support tools based on fundamental principles of ecosystem dynamics.

Historically, management of semi-arid rangelands has emphasized forage production and homogeneous use. The 'scientific backbone' of rangeland management has been the climax-community concept and the Clementsian linear succession/retrogression of plant communities (Figure 1, Clements 1916, Weaver and Clements 1938, Westoby et al. 1989). Realization that many arid and semi-arid rangeland ecosystems do not exhibit linear (and reversible) changes in plant communities led to the development of state-and-transition models by Westoby et al. (1989). These models are based on the assumption that rangeland vegetation exhibits multiple steady state plant communities, rather than a single climax community, and associated transitions (bi-directional) and thresholds (uni-directional, unless substantial external energy is applied) between two states (Figure 2). Transitions are typically the result of natural events (e.g., climate) or changes in management (e.g., shift in grazing intensity) or some combination, and can be of short- or extended duration (Westoby et al. 1989, Svejcar and Brown 1991). Embedded within each steady state are “vegetation phases” which are subtle, reversible shifts in plant composition that may be caused by climate or management. As such, these vegetation phases adhere to the succession/retrogression model within an individual state. Therefore, the state-and-transition model incorporates elements of the traditional climax-community concept within states. The additional capability of state-and-transition models to consider multiple steady states and associated transitions provides a structure which more appropriately addresses rangelands that are not at equilibrium (Fuhlendorf and Smeins 1997).

The seminal paper on state-and-transition models addressed the subject from the perspective of using these models to organize management and research on rangeland ecosystems (Westoby et al. 1989). The authors emphasized that states should be differentiated only if they represented an important change in plant communities (i.e., plant community composition differences) that could influence management. Through use of the state-and-transition model, management on rangelands would emphasize flexibility and timing, encouraging opportunistic management that could take advantage of key ecological processes and/or climatic events to encourage a transition to or maintain a desired state. George et al. (1992) presented a state-and-transition model for California annual grasslands in which transitions were described within the management-process-climate interface (Figure 3). Competition and seedling establishment were alluded to in transitions between states, but not regarding maintenance of a state. This state-and-transition model provided land managers with information relevant to the inducement of transitions between states, but it did not address management or incorporate ecological information pertaining to the maintenance of a state.

State-and-transition models have recently been developed in arid rangelands and shrublands of the southwestern U.S. (Figure 4, Bestelmeyer et al. 2003); similar efforts in grass-dominated, semi-arid rangeland ecosystems, however, are needed. Because the ecological theory of state-and-transition models has attracted most of the attention from researchers, application of these models to management and monitoring has been hindered by an inability to sufficiently characterize states and transitions. The interpretation of state-and-transition models is hampered by inconsistent definitions of states, transitions, ecological thresholds and nonequilibrium ecological concepts (Stringham et al. 2003). There is an emerging appreciation that state-and-transition models need to become more process-based. To accomplish this, research is needed to identify key ecological processes that govern transitions between states, and to incorporate that knowledge into predictive models.

Our efforts aim to take state-and-transition models from the conceptual to the operational domain. Understanding how management can be utilized to create transitions between states will require a more thorough understanding of 1) whether changes really are transitions (as opposed to altered phases), and 2) which ecosystem processes drive changes (whether among states or phases). Although these efforts will extend beyond the planned duration of this proposed project, existing long-term experiments will provide a foundation for initial tests of developed models. Therefore, research is needed to 1) determine if ecological sites of rangeland ecosystems are better characterized by contemporary state-and-transition models than by the traditional Clementsian climax community, succession model, 2) elucidate plant community and soil attributes within states to add breadth to the current descriptions of states, and 3) identify key ecological processes (likely involving C, N and water) that may drive transitions between or maintenance of states.

Grazing management and ecology: Livestock grazing is one of the most prevalent land uses of the world's rangelands and is the primary land management practice on 70% of the western U.S. lands (Council for Agriculture Science and Technology 1974). Because grazing animals select plants at a variety of spatial and temporal scales (Senft et al. 1987), this selectivity can be an ecological driver that modifies competitive relationships among species and leads to vegetation changes in rangeland ecosystems. The management of kinds and classes of livestock, stocking rate, season of grazing and grazing intensity can be used to achieve desired ecological, economic and managerial objectives (Briske and Heitschmidt 1991). Grazing management strategies that maintain vegetation in a desired state or induce a transition to another desired state have practical utility for land managers. Incorporation of those strategies into decision support systems (i.e., state-and-transition models) would be helpful for evaluating the influence of grazing on rangeland ecosystem structure and function. Additionally, a paradigm shift to management for protection of soil and maintenance of plant communities, irrespective of the vegetation state, may be a more realistic goal for grazing management than efforts to attain "climax" plant communities (Hart and Norton 1988).

Although grazing management practices can substantially change vegetation (see reviews by Milchunas and Lauenroth 1993, Jones 2000), there is less understanding regarding rates and drivers of these vegetation changes and associated C, N and water processes. Water is the single most important factor determining the type and productivity of rangelands (Holechek et al. 1998), and N is usually the limiting nutrient to plant production in semi-arid grasslands (Power 1977, Burke et al. 1998). The processes governing the accumulation and decomposition of carbonaceous materials comprising soil organic matter (SOM) are major determinants of plant-available water and N because SOM provides significant water holding capacity in the soil and is the largest reservoir of soil N (Brady and Weil 1999, Follett 2001). Because the transformation processes affecting N and C cycling are closely linked, an evaluation of N cycling requires a concurrent assessment of C dynamics (Stewart et al. 1983). Inclusion of the processes governing water, C and N dynamics into state-and-transition models is necessary to further understand management-induced transitions between vegetation states or phases of vegetation. At this time, the importance of C, N and water processes to state-and-transition models are poorly developed, but efforts to make these models more process-based (e.g., Stringham et al. 2003) should enhance their utility.

Grazing has the potential to substantially alter C and N dynamics in rangeland ecosystems by: (1) modifying the magnitude and relative allocation of C and N to above- and belowground biomass (Briske and Richards 1995, Briske et al. 1996); (2) influencing the quantity and quality of C and N inputs by modifying the species composition and functional diversity of plant communities (Pastor and Cohen 1997, Ritchie et al. 1998); and (3) altering microclimate and the availability of light, water, and nutrients (Ruess 1987, Archer and Smeins 1991). Although grazing may accelerate rates of C and N cycling processes in grazed ecosystems (Ruess and Seagle 1994, Bardgett et al. 1998), its influence on ecosystem C and N storage is often inconsistent and difficult to predict (Milchunas and Lauenroth 1993, Reeder and Schuman 2002). The influence of livestock grazing on the C and N cycles of rangelands is likely to be greatest where herbivory has induced changes in the functional composition of plant communities that alter the use and availability of key resources (Chapin et al. 1997). In various rangeland communities, grazing may modify functional group composition by altering the relative abundance of C_3 and C_4 plant species. Species with these distinct photosynthetic pathways differ markedly in their functional attributes, especially with respect to C-, N-, and water-use characteristics (Pearcy and Ehleringer 1984, Sage and Monson 1999). Consequently, the relative proportion of C_3 and C_4 plants may have a profound influence on the rate and magnitude of various ecosystem processes, including evapotranspiration, primary productivity, decomposition and soil C and N storage (Seastedt et al. 1994, Epstein et al. 1997).

Our research on how grazing management strategies influence vegetation change will focus on changing the intensity and seasonality of grazing to induce desired changes in states of vegetation. C, N and water processes will be studied to provide insight into potential mechanisms that govern changes between states of vegetation and could potentially be used in a predictive manner in clarifying how and when transitions may occur. Knowledge of grazing impacts on soil resources will also provide additional insights into the value or potential (e.g., C storage) of particular ecosystem states.

Invasive weeds: One of the most economically- and ecologically-significant changes in rangeland ecosystems of the western U.S. is the arrival and spread of invasive weeds. Such weeds reduce forage quantity and quality, alter ecosystem function and reduce biological diversity (DiTomaso 2000, Masters and Sheley 2001). Although weed species can be controlled using chemical, biological and/or cultural methods, the ongoing nature of many control methods can result in very high long-term costs (Leitch et al. 1996, Quimby et al. 1991). While weed invasion can be temporary and has been observed to decrease with succession (Rejmanek 1989, Blumenthal et al. 2003), in many cases invasion may represent a relatively permanent transition among vegetation states. Attaining effective weed control therefore requires understanding and, where possible, changing the ecological processes driving weed invasion. For example, if a weed invades because it lacks natural enemies, ongoing chemical control methods may be temporary, and therefore less efficient, than biological control. Conversely, the large investment needed to introduce biological control organisms may not be worthwhile given a weed that invades due to climatic changes. Of particular interest to this Research Unit, therefore, is the question of what mechanisms underlie weed invasion of semi-arid rangelands.

A wide array of hypotheses have been suggested to explain why weeds succeed once they have arrived in a new plant community. These may be broadly categorized into hypotheses related to 1) resource availability and 2) natural enemies (Shea and Chesson 2002). Resources may become available to weeds through resource addition, changes in the timing of resource supply and uptake, and disturbance, which can both add resources directly and reduce uptake by competing species (Davis et al. 2000). In shortgrass steppe and northern mixed-grass prairie resources of primary importance are likely to be water and N (Burke et al. 1998). Several lines of evidence suggest that water availability may increase invasion. First, exotic plant species richness is greater in riparian than upland areas in the shortgrass steppe and northern mixed-grass prairie (Stohlgren et al. 1998). Second, experimental water addition has been found to increase invasion in both shortgrass steppe and tallgrass prairie (Milchunas and Lauenroth 1995, Davis and Pelsor 2001). We hypothesize that two important groups of rangeland weeds may be facilitated by increased winter water: perennial forbs by virtue of their taproots and winter annual grasses by virtue of their early phenology. Nitrogen availability is also closely tied to invasion, with N enrichment frequently leading to high abundance of weeds (Bobbink et al. 1998, Smith et al. 1999) and N reduction leading to decreases in weed invasion (Blumenthal et al. in press). As with increased winter water, perennial forb and winter annual grass weeds might be facilitated by increased N availability, which would reduce competition from grasses with extensive shallow root systems (Lauenroth and Milchunas 1992). Nitrogen addition in the shortgrass steppe can increase abundance of exotic species (Milchunas and Lauenroth 1995), while N immobilization with sucrose has been found to decrease abundance of winter annual grasses (Pashke et al. 2002).

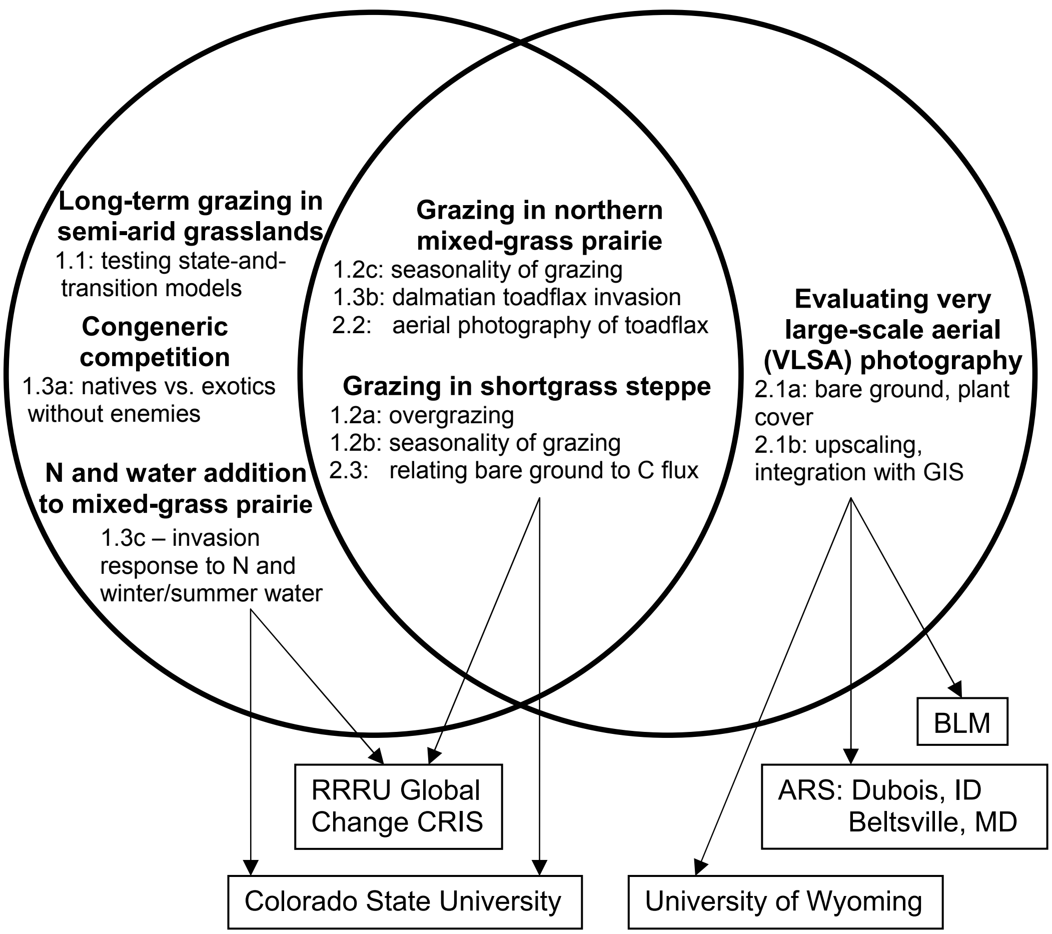
Exotic weeds may also succeed because they have been released from herbivores and diseases present in their native range (Keane and Crawley 2002). Evidence for the enemy release hypothesis comes from successful biological control, greater numbers of diseases on native than exotic species (Klironomos 2002, Mitchell and Power 2003), differential enemy presence in native and exotic ranges (Wolfe 2002) and regulation of native plant species by natural enemies (Maron and Vila 2001). In the shortgrass steppe and northern mixed-grass prairie potentially important enemies include vertebrate and invertebrate herbivores and both above- and below-ground pathogens (Coupland 1992, Lauenroth and Milchunas 1992). Of these, domestic livestock are both the best studied and the easiest to manage. Livestock grazing can either facilitate (Hobbs 2001) or inhibit (Milchunas et al. 1990) weed invasion, depending on both the evolutionary history of the ecosystem (Mack and Thompson 1982), and the particular weeds and grazers (Walker et al. 1994). Cattle grazing intensity is inversely related to exotic species richness in shortgrass steppe (Milchunas et al. 1990).

Our research on the role of natural enemies will address two questions. In conjunction with our studies of how grazing management strategies influence vegetation, we will examine the effects of timing and intensity of grazing on perennial forb and winter annual grass weeds. We will also examine resource competition between exotic weeds and native congeners in the absence of natural enemies to begin to understand the relative importance of natural enemies and resource availability to rangeland weed invasion.

The management of complex native rangeland ecosystems requires both a fundamental understanding and characterization of ecosystem dynamics (Objective 1) and tools to allow managers to monitor those dynamics (Objective 2, pages 16-22). The conceptual diagram below illustrates the linkage between the two Objectives (overlap of circles), which focuses on two new experiments assessing the interrelationships between grazing practices, weed invasion and the ability to monitor changes in ecosystem dynamics. Experiments within each objective are shown in bold font followed by the subjects of hypotheses for each subobjective tested within each experiment (numbered, see following text). Arrows depict collaborations with other ARS, University and Federal agency projects.

Objective 1:
Understanding and characterization of ecosystem dynamics
1.1 Test NRCS state-and-transition models
1.2 Study intensity and timing of grazing
1.3 Learn how enemies and resources influence weeds

Objective 2:
Tools to monitor ecosystem dynamics
2.1 Develop VLSA monitoring methods
2.2 Monitor sparse weed populations with VLSA
2.3 Determine ecosystem composition/ function with VLSA monitoring



<u>Objective 1</u>: Increase the accuracy and utility of state-and-transition models by testing their ability to classify and predict vegetation change, and learn how grazing (intensity and season of use), plant resources (N and water), and exclusion of plant enemies (insects and pathogens) influence vegetation change in northern mixed-grass prairie and shortgrass steppe.

Objective 1.1. Test NRCS-developed state-and-transition models in the northern mixed-grass prairie (Figure 5) and shortgrass steppe (Figure 6).

Hypothesis 1.1. **The state-and-transition models for a) MLRA 67 (Loamy 12-17" precipitation zone) in the northern mixed-grass prairie and for b) MLRA 67B (Loamy) in the shortgrass steppe accurately characterize the plant communities of these ecosystems**. Current state-and-transition models capture the influence of grazing practices on vegetation change, but do not incorporate knowledge pertaining to soil water and N dynamics, which are primary drivers for the existence, type and functioning of grassland ecosystems. This absence may lead to some incorrect conclusions about the character and dynamics of vegetation states. For instance, it is well known that heavy grazing leads to the elimination of cool-season grasses in these ecosystems (Figures 5 & 6), but there is no information available as to what management strategy might reverse this trend, or how seasonal dynamics in water and N availability might be involved. For example, does the grazing-induced transition to a blue grama sod with a minor to non-existent cool-season grass component alter the spatial and temporal partitioning of N and water to benefit the shallow-rooted, N- and water-use efficient warm season grasses over the relatively deep-rooted, less water-use efficient cool-season grasses, thereby preventing their re-establishment? Answers to these types of questions are needed to further develop and improve state-and-transition models. The use of long-term data sets and the collection of ancillary soil water, C and N data in recent research will 1) allow a testing of state-and-transition models of two different grasslands with twenty-one years of research in the northern mixed-grass prairie and sixty-three years of research in the shortgrass steppe, and 2) initiate a preliminary analysis of relationships between important C, N and water variables and vegetation state changes induced by long-term grazing practices.

Experimental Design (Northern mixed-grass prairie): A study was begun in 1982 to evaluate the responses of vegetation, soils and livestock performance in northern mixed-grass prairie to 3 grazing strategies (continuous season-long, time-controlled rotation 8-paddock system, and time-controlled rotation 24-paddock system) at 3 stocking rates (light: 0.21 steers ha^{-1}, moderate: 0.42 steers ha^{-1} or heavy: 0.56 steers ha^{-1}) in replicated pastures. In addition, 2, 0.25 ha exclosures were established in 1982. The study site, located about 10 km northwest of Cheyenne, Wyoming, is the High Plains Grasslands Research Station. Pastures on this study are typically grazed by yearling steers each year from early June to late October. Animal performance will be determined by weighing animals at the beginning and end of the grazing season. Peak standing crop will be determined annually in late July from 4 permanently located 1.5 X 1.5 m cages in each pasture. These cages will be moved 2 meters in a randomly determined cardinal direction each spring prior to initiation of grazing. Biomass will be clipped to ground level in 2, 20 X 50 cm plots per cage and separated by species, dried and weighed. Two permanently located 50-m transects in each pasture will be sampled annually for basal cover by species, bare ground, litter cover, dung cover, canopy cover by species and density (number of stems) by species using 25 randomly located 20 cm X 50 cm plots for each transect. Ordination techniques (McCune and Grace 2002) will be used to determine if vegetation attributes differ with respect to established treatments. Observations on vegetation composition will be compared to predicted vegetation composition from the NRCS-developed state-and-transition model to determine if re-formulation of the model is necessary. To initiate a preliminary analysis of relationships between important C, N and water variables and vegetation state changes induced by long-term grazing practices, we sampled soils in May 2003 to a depth of 1 m at 5 locations along each of the transects in the exclosures and continuous season-long pastures (but not the time-controlled rotation pastures). These soil samples will permit temporal comparisons to the C and N storage results previously reported by Schuman et al. (1999) from these same treatment pastures. Preliminary analyses of C, N and water content will form the foundation for future experiments that will target specific C, N and/or water processes that may govern transitions between states, and determine if they can be used in a predictive manner in clarifying how and when transitions may occur. At each soil core location, 1, 10 cm X 1 m core and 1, 4.6 cm X 1 m core were taken. Both cores were partitioned into 0-5, 5-15, 15-30, 30-45, 45-60 and 60-100 cm increments. These depth increments were selected to partition the soil by major horizons. The smaller diameter core will be used for determination of bulk density using methodology of Blake and Hartge (1986). The bulk density data will be used to convert soil organic C and N concentrations (mg kg^{-1}) to C and N mass (kg ha^{-1}). Soil from the larger diameter core will be used for determinations of: gravimetric water content, total soil C, SOC, soil inorganic C, total soil N, particulate organic matter C and N, water soluble organic C and N, 3-day incubations to estimate respired CO_2 and mineralized N, and microbial biomass C and N. Because SOM is not homogeneous in its physical or compositional nature, it is generally differentiated into different pools of varying turnover rates (Parton et al. 1988), and the analyses we have selected will estimate the sizes of the different pools. A small percentage (generally <3%) of total SOM is found in a rapidly cycling "active" fraction, with turnover times ranging from hours to months (Parton et al. 1988, Burke et al. 1997). This active fraction is estimated by water soluble organic C and N (Davidson et al. 1987), microbial biomass, and 3-day incubation estimates of respired CO_2 and mineralized N (Franzluebbers et al. 2000). Approximately 20-40% of SOM is in an "intermediate" or "slow" pool, which has decadal turnover times and is estimated by particulate organic matter (Cambardella and Elliott 1992). The majority of SOM (approx. 60-80%) is "recalcitrant" in nature with turnover times ranging from centuries to millennia (Parton et al. 1988, Burke et al. 1997). This large pool is estimated by subtracting "active" and "recalcitrant" pools, as well as inorganic C, from total soil C. Ordination techniques (McCune and Grace 2002) will be used to determine if soil attributes differ with respect to established treatments, and soils data will be used to broaden descriptions of vegetation states.

Experimental Design (Shortgrass steppe): In 1939, a replicated study of 3 grazing intensities (light, moderate and heavy) was begun on shortgrass steppe at the Central Plains Experimental Range, located about 20 km northeast of Nunn, Colorado. Over the years replications were dropped until by 1960, a single pasture (130 ha) of each of the 3 intensities remained. Each pasture contains a 0.8 ha exclosure established in 1939. Yearling Hereford heifers typically graze pastures from mid-May to late-October at light, moderate or heavy stocking rates of 0.12, 0.15, and 0.19 heifers ha^{-1}, respectively. Target residue levels are 500, 335 and 224 kg ha^{-1} for the light, moderate and heavy grazing intensities, respectively. Animal performance will be determined by weighing animals every 4 weeks. Peak standing crop for each pasture will be determined in mid-August from randomly selecting 15 of the 60 permanent, systematically spaced 1.5 X 1.5 m cages. Biomass will be clipped to ground level in 2, 20 X 50 cm plots per cage and separated by species, dried and weighed. All 60 of the permanently located cages in each pasture will be sampled annually in early August for basal cover by species, bare ground, litter cover, dung cover, canopy cover by species and density (number of stems) by species using a 20 cm X 50 cm plot in each cage. Soils will be sampled to a depth of 1 m in June 2004 at areas previously sampled in 1995 in each pasture and the ungrazed exclosure to permit temporal comparisons to Derner et al (in review) and Reeder et al. (in press). Soils will be collected and processed as described for the northern mixed-grass prairie. We hypothesize that the soil beneath the blue grama sod of the heavy grazing treatment will be higher in organic C than the soils beneath the other grazing treatments, because blue grama transports more of its photosynthate below ground than cool-season grasses (Coupland and Van Dyne 1979). We also hypothesize that long-term heavy grazing will increase the C:N ratio of the SOM and decrease the N-supplying capacity of the soil. Although the C lost to animal tissues by grazing is replenished through photosynthesis, annual inputs of N by deposition and N_2 fixation are small and likely insufficient to replenish N losses (Woodmansee 1979). Ordination techniques (McCune and Grace 2002) will be used to determine if vegetation and soil attributes differ with respect to established treatments. Observations on vegetation composition will be compared to predicted vegetation composition from the NRCS-developed state-and-transition model to determine if re-formulation of the model is necessary. In addition, the soil data will be used to broaden descriptions of vegetation states.

Milestones for Objective 1.1: Collection of soil data from northern mixed-grass prairie (May 2003); Collection of vegetation data northern mixed-grass prairie (July 2003-2007); Collection of vegetation data from shortgrass steppe (August 2003-2007); Collection of soil data from shortgrass steppe (June 2004); Comparison of collected data and NRCS-developed state-and-transition model for shortgrass steppe and northern mixed-grass prairie (2006)

Objective 1.2: Assess management strategies that influence the abundance and diversity of desired plant species through changes in the intensity and seasonality of grazing.

Hypothesis 1.2a: **Severe overgrazing of shortgrass steppe will: 1) decrease plant canopy and basal cover of desired grasses, 2) decrease plant richness and diversity, 3) increase bare ground, 4) have no effect on soil water, and 5) increase weed invasion.** Grazing experiments in the shortgrass steppe have heretofore not been designed to push the ecological limits of this ecosystem. For instance, it is well known that heavy grazing results in a blue grama/buffalograss sod vegetation state (Figure 6), but it is unknown if overgrazing will induce a transition from this vegetation state to another, and if a transition occurs, what the plant community of the new vegetation state would be? This experiment will determine trajectories and rates of vegetation change with severe overgrazing and assess the effects of these changes on soil water and potential weed invasion.

Hypothesis 1.2b: **Changing the seasonality of grazing from traditional season-long to early spring, high intensity grazing in shortgrass steppe will: 1) decrease abundance and diversity of cool-season grasses, 2) decrease net ecosystem production, 3) have no effect on soil water, 4) decrease C storage, 5) increase N in upper soil layers and 6) increase weed invasion.** The decrease in cool-season grasses is necessary to modify habitat conditions for a specific wildlife species, mountain plover (*Charadrius montanus*), a candidate for listing as a threatened bird species. These habitat conditions include very short vegetation with a high abundance of localized bare ground. Traditional rangeland management practices have emphasized light- to moderate stocking rates with season-long grazing to increase animal performance and maintain mid- to high-seral vegetation and limited bare ground. This experiment will test whether livestock can modify shortgrass steppe vegetation to create needed habitat conditions for this bird species and also assess the effects of these changes on availability of N, seasonal CO_2 fluxes, soil water and potential weed invasion.

Experimental Design: A planned long-term (>10 years) study to begin in 2004 will address the role of severe overgrazing and spring grazing on vegetation change in semi-arid shortgrass steppe at the Central Plains Experimental Range. Two, 65 ha pastures with a history of continuous season-long moderate grazing (late May to mid-October) will be grazed at twice the moderate intensity, 6.5 ha heifer^{-1}. The goal of this grazing intensity will be to achieve a desired minimum residual vegetation threshold of 90 kg ha^{-1}. This threshold represents the lower end of ungrazed forage where emergency feed may be necessary for animal production (90 to 180 kg ha^{-1}, Lauenroth & Milchunas 1992, Bement 1969). Once this threshold is achieved during the grazing season, cattle will be removed from the pastures and placed on adjacent pastures until the residual value has increased to 180 kg ha^{-1}. At that time, cattle will be placed back on the treatment pastures to achieve the desired minimum residual vegetation threshold. To reduce impacts on individual animal performance, cattle will be rotated bi-monthly with those in a neighboring 130 ha pasture. Two, 130 ha pastures with a history of continuous season-long moderate grazing (late May to mid-October) will be grazed at very high intensity (1.5 ha $heifer^{-1}$) during the early spring grazing period (mid-March to late May). The goal of shift in seasonality of grazing, from summer to spring, is to determine if this grazing practice can modify habitat conditions such that they are more conducive for mountain plover (*Charadrius montanus*), a potentially threatened bird species that is principally found on the shortgrass steppe during the breeding (late March to late April) and chick-rearing (May) seasons. In each pasture, a 15-m radius circular plot will be centered on a randomly determined point in a level upland area and a level lowland area. Fifty-four, 20 cm X 50 cm plots will be systematically located in each of the circular plots. In late-May (spring grazing pastures) and late-June (summer grazing pastures) of each year, the following will be monitored in each 20 cm X 50 cm plot: basal cover by species; bare ground, litter cover, dung cover, canopy cover by species and density (number of stems) by species. Species richness (S = number of species per quadrat), evenness (Pielou's J index = H'/ln S) and Shannon species diversity index [$H' = -\Sigma (p_i \cdot \ln p_i)$; p_i = proportional abundance of species *i* within the quadrat, Magurran 1988] will be calculated on a plot basis. Sampling of these vegetation attributes will be conducted by the Shortgrass Steppe Long-term Ecological Research (SGS-LTER) vegetation crew. Baseline vegetation information was acquired for aforementioned attributes in June 2003. These attributes will be measured annually to determine rates and trajectories of change. To determine whether spring grazing and severe overgrazing also lead to increased weed invasion, 10 randomly located 2 m X 2 m plots in each upland and lowland area will be seeded with dalmatian toadflax (*Linnaria dalmatica*). Within each plot, dalmatian toadflax canopy cover and bare ground will be measured for the duration of the experiment. In addition, a 2 cm X 10 cm soil core will be taken monthly from each of these 2m X 2 m plots for determination of available N and soil water content. Two, 65 ha pastures with a history of continuous season-long grazing (late May to mid-October), at a moderate intensity of 6.5 ha $heifer^{-1}$ will serve as controls for this experiment. CO_2 flux rates, soil water content (to 1 m depth) and pasture-level assessment of bare ground (see Objective 2.3 for further details) will also be evaluated. In late winter of 2004, 2 Bowen Ratio Balance systems (BREB; Campbell Scientific, Logan, UT) and 2 Sentek soil water tubes (Sentek Pty. Ltd., Stepney, South Australia) will be installed in the control pastures, and 2 each will be installed in the early spring grazing pastures. The BREBs and soil water tubes will be operated continually throughout the year, and will provide daily measurements of ecosystem CO_2, H_2O and energy fluxes, and monitoring of the soil water by depth to 1 meter depth with Sentek tubes. An automated rain gauge will monitor site precipitation. For characterization of baseline soil properties, soils will be sampled to a depth of 1 m in May 2004 from 5 random locations within each of the circular plots, and composited by depth increment. Soils will be analyzed as described in Objective 1.1. In early spring 2004, 5 resin bags will be installed at 5 cm depth within each circular plot, and removed in late fall 2004, to characterize growing season net N mineralization in the surface soil. Data will be analyzed using a two-factor ANOVA, with grazing treatment (season-long moderate grazing, season-long severe overgrazing and heavy spring grazing) and landscape position (upland and lowland) as the main factors.

Hypothesis 1.2c: **Changing the seasonality of grazing to late summer grazing in northern mixed-grass prairie will: 1) increase abundance and diversity of cool-season grasses, 2)**

decrease abundance and diversity of warm-season grasses, 3) increase C storage, and 4) decrease C cycling. Although it is well-documented that season-long grazing increases the abundance of warm-season grasses such as blue grama at the expense of cool-season grasses in northern mixed-grass prairie (Figure 5), little is known concerning management strategies that can be implemented to reverse this decline in cool-season grasses. This experiment will test whether changes in seasonality of grazing induce desired vegetation change and determine effects on C cycling and storage.

Experimental Design: Four pastures with a history of continuous season-long (early June to mid-October) grazing will be included in a long-term (>10 years) study that began in 2003 to address the effects of changing seasonality of grazing on northern mixed-grass prairie at the High Plains Grasslands Research Station. Two of the pastures are 72 ha each and have been grazed at a heavy (5.1 ha cow-calf pair^{-1}) grazing intensity for the past 11 years, and the other 2 pastures are 88 ha each and have previously been grazed at a moderate (6.3 ha cow-calf pair^{-1}) grazing intensity. Whereas previous treatments evaluated the influence of moderate and heavy stocking rates using continuous season-long grazing, the new treatments will emphasize management options that may bring about increased abundance of cool-season grasses to the vegetation community. The stocking rate treatments will be maintained on the same pastures, but the season of use and stocking density (number of animals per unit land area) will be altered. Continuous season-long grazing will be replaced by intensive early-season (IES) or intensive late-season (ILS) grazing. Both the IES and ILS grazing systems double the number of livestock in a given pasture, but livestock graze these pastures for only half of the grazing season. The IES grazing system is targeted to coincide with the prevailing major growth period for vegetation in the northern mixed-grass prairie (early June-mid August), while allowing re-growth in the late summer and fall months. In contrast, the ILS grazing is targeted to allow plants to grow during their peak growth period, and then be consumed by livestock (mid August-mid-October). One pasture from each grazing intensity will be randomly assigned to the IES or IES treatment. A continuous season-long grazed pasture, at a moderate grazing intensity, will serve as a control for this experiment. Peak standing crop will be determined annually in mid-July from 8 permanently located 1.5 X 1.5 m cages in each pasture. These cages will be moved a few meters in a randomly determined cardinal direction each spring prior to initiation of grazing. Biomass will be clipped to ground level in 2, 20 X 50 cm plots per cage and separated by species, dried and weighed. Four permanently located 25-m transects in each pasture will be sampled annually for basal cover by species, bare ground, litter cover, dung cover, canopy cover by species and density (number of stems) by species using 12 randomly located 20 cm X 50 cm plots for each transect. Species richness, evenness and diversity will be calculated on a plot basis as described in Objective 1.2b. Baseline vegetation information was acquired for the aforementioned attributes in July 2003. Animal performance will be determined by weighing animals prior to (early June), middle of (mid-August) and at the end (mid-October) of the grazing season. Soils will be sampled to a depth of 1 m in May 2004 at 2 locations along each transect. Soils will be sampled and processed as described in Objective 1.1. Monthly soil samples will be collected during the growing season to assess seasonal changes in organic C and N pools. Samples will be collected from the A-horizon (0-5 and 5-15 cm) at 2 locations along each transect. We hypothesize that grazing management will alter the “active” and “intermediate” pools before a change in vegetation state is observed, but change in the size of the “recalcitrant” pool will occur only after a change in vegetation state has occurred. We also hypothesize that changes in the ratios of labile C and N to total C and N, and labile C to labile N, can serve in a predictive manner in clarifying how and when transitions may occur. Because this is a non-replicated study, the scope of inference is limited to the observed plots. Data will be analyzed using a single-factor ANOVA.

Milestones for Objective 1.2: Change from season-long to IES and ILS in northern mixed grass prairie (June 2003); Collection of vegetation data from shortgrass steppe (May and June 2003-2006); Collection of vegetation data from northern mixed grass prairie (July 2003-2006); Collection of soil data from northern mixed grass prairie (May 2004); Collection of soil data from shortgrass steppe (May 2004); Change from moderate season-long grazing to heavy spring grazing in shortgrass steppe (March 2004); Change from moderate season-long grazing to severe overgrazing in shortgrass steppe (June 2004)

Objective 1.3. Assess the relative importance of enemy release, resource availability and soil disturbance in driving perennial forb and winter annual grass invasion of northern mixed-grass prairie and shortgrass steppe.

Hypothesis 1.3a: **In the absence of natural enemies the outcome of resource competition between native and exotic congeners will not vary predictably with species origin.** While a lack of natural enemies is commonly assumed to account for the preponderance of exotic species among invasive weeds, many exotic species have also been shown to compete well under conditions of high resource availability. This experiment will test whether exotic weeds differ consistently from native species in competitive ability under varied conditions of resource availability.

Experimental Design: Twelve congeneric pairs of native and exotic species will be planted together as seed in 20 cm diameter X 50 cm deep pots using sterile soil in a greenhouse. Pots will be exposed to high and low levels of water and N. Measurements will include plant biomass, N-use and water use efficiency, and N and water availability. The experimental design will include the 3 factors (water, N and species origin), blocked by location in the greenhouse with 5 replications of each species pair for a total of 240 pots [12 pairs X 2 level of N X 2 levels of water X 5 reps]. Seeds of native and exotic species will be collected from field populations during the summer/fall of 2003. Enemies will be removed by conducting the experiment in the greenhouse, sterilizing the soil prior to planting, and periodically applying fungicide, bactericide and insecticide to plants and soil. Pre-experiments will be conducted to determine the effectiveness of sterilization, and the influence of sterilization on nutrient availability. Soil nutrients (except for N) will be adjusted to correct for the altered supply expected in a sterile soil. In order to verify the effectiveness of soil sterilization and resource addition treatments a subset of pots will be left unplanted. These will be used to assess microbial respiration and measure N and water availability (4 treatment combinations X 5 reps = 20 pots) over time. Germination (density counts) will be measured until it peaks. At that point plants will be thinned to ensure equal numbers of plants of each species in each pot. Biomass will be measured by species and organ (leaf, stem, root, and reproductive tissue) at the end of the experiment. Other measurements may include root and shoot N content, leaf area, root length and rates of photosynthesis/respiration.

Hypothesis 1.3b: **Dalmatian toadflax (*Linnaria dalmatica*) abundance in northern mixed-grass prairie is positively related to south-eastern facing slopes and negatively related to grazing intensity.** Dalmatian toadflax is a problematic, perennial forb invader of rangeland in the northern mixed-grass prairie. Little is known, however, about the environmental conditions that contribute to its increasing abundance. Initial observations suggest that southeast slopes, which receive more winter water, and ungrazed areas contain higher densities of dalmatian toadflax. This study will attempt to quantify relationships between slope, soils and grazing intensity and dalmatian toadflax abundance.

Experimental Design: This is an observational study using extant dalmatian toadflax populations within pastures previously described in Objective 1.2c (moderate and heavy grazing intensities; intensive early- and late-season grazing). We will measure dalmatian toadflax populations in these pastures in 2003-2006 by counting stems, which are readily visible in mid-summer, from very large-scale aerial photography (see Objective 2.2). Two hundred 12.9 m X 8.6 m nadir photographs will be taken in each pasture. Photographs will be analyzed visually and with a color recognition program (ERDAS Imagine) for the number of stems and flowering stems in each photograph. In order to measure the accuracy of the dalmatian toadflax stem counts, a subset of photograph coordinates will be flagged prior to photographing and then revisited to determine the exact location of the photograph. Dalmatian toadflax stems within each photographed area will be counted, clipped, dried and weighed. The resulting dalmatian toadflax stem number and biomass will then be regressed against the number of dalmatian toadflax stems counted in the photograph. Slope, aspect and soil type will be taken from available topographic and soils maps according to GPS coordinates for each photograph. Relationships between dalmatian toadflax abundance and soil type, slope, aspect and grazing treatment will be determined using multiple regression. In addition, 6, 1 m X 1 m X 1 m cages were constructed around existing toadflax plants in June 2003 within each of the pastures. Cages were placed around randomly located toadflax plants approximately 75 m from the lowest elevational point (3 cages) and highest elevational point (3 cages) within each pasture. Random locations were chosen to ensure at least 50 m separation between cages. Stem height, length of longest leaf, leaf number and branch number were measured for all toadflax plants within each cage. Identical measurements were taken within 2, 1 m X 1 m plots outside each cage. Uncaged plots were centered on the nearest toadflax plants greater than 10 m from the center of each cage; one plot was located to the east and one to the west of each cage. Measurements will be repeated annually in June for both caged and uncaged plots.

Hypothesis 1.3c: **Increased winter (but not summer) water availability, and increased N availability will increase invasion of northern mixed-grass prairie by perennial forbs and winter-annual grasses.** Since both water and N availability are expected to change with global climate change and both factors are known drivers of weed invasion, the impact of predicted changes in water availability and the interactive effects of water and N availability, which are likely to be important in semi-arid ecosystems, on weed invasion warrant investigation.

Experimental design: This experiment will consist of 3 factors: 1) winter water - ambient vs. increased (using a snow fence), 2) summer water - ambient, increased (by supplemental watering), decreased (using a rainout shelter) and 3) nitrogen - ambient, increased (with ammonium nitrate), decreased (with sucrose). Treatments will be arranged in a split-split plot design: summer water treatments will be within 2.5 m X 2.5 m subplots (separated by 1 m buffers) within winter water treatments and nitrogen treatments will be within 1 m X 1 m subplots (separated by 0.5 m X 0.5 m buffers) within summer water treatments. Water treatments will be implemented with the assistance of Dr. Jeff Welker, who is conducting an experiment with identical water treatments adjacent to this experiment. Rainout shelters, targeting 66% reduction of ambient rainfall, will consist of transparent rain gutters located 1 m above the ground that drain several meters from the plot. Supplemental summer watering will be conducted weekly and the amount added will be adjusted to double the amount of water that fell the previous week. Two g m^{-2} N, as ammonium nitrate, will be added to N addition plots in May and July each year. Fifty g m^{-2} C, as sucrose, will be added to N reduction plots in May, July, September and November each year. Three weed species, dalmatian toadflax (*Linaria dalmatica*), leafy spurge (*Euphorbia esula*) and downy brome (*Bromus tectorum*) will be planted within 0.5 m X 0.5 m subplots. The remaining subplot will be used to measure treatment effects on nitrogen and water availability. Weeds will be planted in the fall, and germination will be measured weekly in both fall and spring until it tapers off. Height, diameter and leaf size will be measured on all weed stems at peak biomass each year for 3 years. After 3 years all weeds will be harvested, dried, weighed and analyzed for N content. Measurements of N and water will not be possible within each sub-subplot. Because, however, we are interested primarily in the environment experienced by the weeds (rather than the effect of the weeds on the environment) we can characterize this with the non-seeded section of each subplot used for soil sampling. Resin bags will be used to attain a relative measure of N availability. Soil water availability (to a depth of 20 cm) will be measured gravimetrically, once each month during the growing season. Water availability deeper in the soil profile will be measured in an adjacent experiment employing identical water treatments.

Milestones for Objective 1.3: Greenhouse congener study – seed collection, sterilization pre-experiments (Nov 2003), planting full experiment (Dec 2003), Harvesting (March 2004); Dalmatian toadflax study – caging (June 2003), photography (July 2003), ground truthing (July 2003) photograph processing/analysis (Dec 2003), cage monitoring (2004 - 2013); water/N manipulation study – construction, initial treatment application and planting (Oct 2003), final destructive harvest (2006)

Contingencies for Objective 1: If environmental conditions prohibit vegetation and soil sampling in 2003, efforts will be made to conduct sampling in 2004 or 2005. If the planned overgrazing study cannot begin in 2004, efforts will be taken to begin the study in 2005. Dalmatian toadflax planted in the shortgrass steppe may germinate poorly. To avoid this problem, we will plant seeds in the fall and, if necessary, water plots to promote germination the following spring. If greenhouse sterilization techniques are ineffective, implementation of the greenhouse experiment will be delayed until satisfactory enemy exclusion treatments are designed.

Management for Objective 1: J.D. Derner will manage the changes in grazing treatments and collection of vegetation data in the shortgrass and northern mixed-grass prairie ecosystems. J.D. Reeder and G.E. Schuman will manage collection of soils data from two ecosystems. D.M. Blumenthal will manage the collection of information pertaining to invasive weeds for both ecosystems. J.A. Morgan will manage the collection of the CO_2 flux and soil water data from the shortgrass steppe.

Necessary Collaborations for Objective 1: Collaboration with Bill Lauenroth (Colorado State University) on grazing experiments in the shortgrass steppe. Collaboration with Jeff Welker (Colorado State University, Natural Resource Ecology Laboratory) on the water availability experiment in the northern mixed-grass prairie.

Scientific Background: Literature Relevant to Objective 2.

Accurate monitoring of rangeland ecosystems is fundamental to ecologically-sustainable rangeland management. Yet, monitoring rangeland ecosystems has relied predominantly on limited sampling, targeting "key" areas within watersheds/allotments, primarily because of budgetary and personnel restrictions. Changes in monitoring tools and methods are needed to more effectively assess rangeland ecosystems (NRC 1994, Donahue 1999), and these changes should be driven by three factors. First, a shrinking pool of trained professionals necessitates that monitoring tools need to reduce the labor required to accurately obtain data. Second, emergent technological advances in digital imagery and computer technology provide opportunities for quickly collecting, storing and accessing large quantities of high quality data. Third, realization that many semi-arid ecosystems may be more properly characterized using state-and-transition models with multiple steady states, rather than with a single climax community, diminishes the utility of many succession-based monitoring tools and methods (e.g., range condition, Dyksterhuis 1949). It is clear that there is both a need for and an opportunity to develop rapid, reliable and repeatable monitoring tools that are applicable over extensive areas (i.e., watersheds, allotments) and detect ecologically-important changes (Brady et al. 1995). In order to monitor vegetation states and transitions between states, monitoring tools will need to accurately assess indicators that provide information pertaining to both rangeland ecosystem structure and function. If efforts are successful, monitoring tools will contribute to effective management of rangeland ecosystems.

Suites of indicators for assessing the health of rangeland ecosystems have been proposed (Pellant et al. 2000). In addition, the Sustainable Rangelands Roundtable (Rowe et al. 2002) has recently identified 64 indicators of sustainability, of which 26 pertain to soil, water, plant and animal resources and productive capacity (unpublished handout). Although rangeland ecosystems are multivariate in nature and there are a number of relevant plant, soil and water indicators (Karr 1992), it is clear that monitoring all of these indicators is not a realistic goal, given budgetary and labor limitations. Of the indicators identified for monitoring rangeland health, ground cover and its inverse, bare ground, have been the most discussed because of their direct relationship to soil conservation (NRC 1994, Society for Range Management, Task Group on Unity in Concepts and Terminology 1995). For example, increasing bare ground has been consistently correlated with increasing soil erosion in many rangeland systems (Branson et al. 1972). In addition, plant cover has been promoted as the best single measure of a plant species' importance in a community (Taylor 1986 citing Lindsey 1956 and Daubenmire 1959), and changes in plant cover have been demonstrated with grazing treatment differences in shortgrass steppe (White et al. 1991), sagebrush steppe (Bork et al. 1998) and in riparian areas (Popolizio et al. 1994).

Plant cover is directly related to important ecosystem functions including assimilation of CO_2 (LeCain et al. 2002, Frank and Karn 2003, Wylie et al. 2003) and the energy balance of rangelands (Li et al. 2000). As such, understanding the dynamics of plant cover is critical in evaluating net primary and ecosystem production, C and N cycling, and hydrology, and scaling up those critical ecosystem functions to landscape levels (de Wit 1978, Ehleringer and Field 1993). Common measurements of plant cover include intensive hand-clipping or mowing for determination of leaf area index (Brown and Blaser 1968, Morgan and Brown 1983a,b), non-destructive estimates of cover (Daubenmire 1959, Waren-Wilson 1963, LeCain et al. 2002) or spectral measurements like the normalized difference vegetation index (NDVI), which has proven to be a good predictor of biomass and leaf area index (Frank et al. 2003, Wylie et al. 2002). Success in relating cover estimates to canopy level fluxes of CO_2 and H_2O have generally been good, with strong relationships observed in improved pasture monocultures (Morgan and Brown 1983a,b), as well as in more variable sagebrush steppe (Wylie et al. 2003) and northern plains grasslands (Frank and Karn 2003). However, little has been done to incorporate such knowledge of plant cover dynamics and associated ecological mechanisms into considerations of rangeland health.

The value of a permanent photographic record, its relatively low cost, and its potential as an objective data-collection method, are reasons for using photography as an effective monitoring tool. Use of vertical photography for monitoring vegetation was first reported by Cooper (1924). Since then there has been steady development of tools and methods for acquiring and using ground images for this application. Large-scale aerial photography was first used to examine plants and plant communities in identifying plant diseases and calculating timber-stand volumes (Lossee 1953, Colwell 1956) at scales from 1:7,200 (Lossee 1953) to 1:600 (Pope 1958, Aldrich et al. 1959). Recently, methods for acquiring low-altitude, very large-scale (VLSA) imagery (scale $\geq$1:500) have received considerable attention (e.g, Louhaichi and Johnson 2001, Aerosonde 2002, Hansen and Ostler 2002). Platforms for acquiring VLSA imagery include portable camera supports, poles, balloons, dirigibles, kites, radio and computer-controlled unmanned aircraft, ultralight aircraft and ultralight-type fixed-wing airplanes, and helicopters (Tueller et al. 1988, Hinckley and Walker 1993, Hansen and Ostler 2002, Aerosonde 2002, Booth et al. 2003). Helicopters and long-range unmanned aircraft are expensive (Aerosonde 2002). Among the remaining platforms, the ultralight-type, 3-axis, fixed-wing airplane appears to be the most practical for low and slow flight over extensive areas ($\geq$100 km^2) for systematic, intermittent, aerial sampling (Abel and Stocking 1987). The utility of photography as an effective monitoring tool has been enhanced with the development of software packages that are capable of measuring cover and bare ground from an image (e.g., Louhaichi and Johnson 2001, Richardson et al. 2001, Hansen and Ostler 2002). Although cover measurement by image analysis has some inherent errors, it appears that for many cover types image analysis is more precise (Richardson et al. 2001) or at least not different from manual measurements and can be done in minutes versus hours or days (Louhaichi and Johnson 2001, Hansen and Ostler 2002, Booth et al. 2003).

The arrival and spread of invasive weeds has significantly changed many rangeland ecosystems (see above). The cost of adequately detecting and mapping these weed infestations is currently prohibitive (Lass et al. 1996). Current aerial methods employ large- and small-scale color infrared photography (Everitt et al. 1994, 1995a, 1995b, and 2001), multispectral imagery (Carson et al. 1995, Lass et al. 1996, Lass and Callihan 1997, Lamb 1999, Lass et al. 2000) and video imagery (Everitt et al. 1992, 1993, 1995b,1996). Computer image analysis for automated data processing is also being used (Everitt et al. 1994, 1996, 2001). Because image resolution and plant-growth stage are critical factors for maximum weed detection with minimal error (Lass et al. 2000), the previously stated methods are adequate for large woody plants or large stands, but not for detecting and mapping smaller herbaceous plants interspersed with other vegetation. VLSA imagery, with sub-centimeter resolution (Booth et al. 2003), however, offers the potential to detect and map plant populations, and correlate these to landscape patterns.

Our research on the tools to allow managers to monitor ecosystem dynamics will focus on 1) evaluating the effectiveness of VLSA photography, in combination with computer image measurement techniques, to monitor bare ground and plant cover over extensive areas (i.e., allotments, watersheds) in semi-arid rangelands, 2) utilizing VLSA to study landscape scale patterns of weed invasions and 3) correlating changes in bare ground and plant cover from VLSA photography with net ecosystem production and water and energy fluxes.

<u>Objective 2</u>: Develop very large-scale aerial (VLSA) photography and ground photography methods to accurately monitor bare ground, plant cover and plant communities in sagebrush and shortgrass steppe and northern mixed-grass prairie.

Objective 2.1. Evaluate effectiveness of VLSA photography and ground photography, in combination with computer image measurement techniques to monitor bare ground and plant cover over extensive areas (i.e., pastures, allotments, watersheds) of sagebrush and shortgrass steppes and northern mixed-grass prairie. Develop a GIS application for VLSA data management such that the application can be queried about specific concerns (e.g., what is the average bare ground for allotment X, or for the sagebrush community within allotment Y). Increase the value of space imagery by developing methods to interface with VLSA images or data (upscaling).

Hypothesis 2.1.a. **VLSA photography and ground photography can accurately monitor bare ground and plant cover by plant functional group (grasses, forbs, shrubs) in sagebrush and shortgrass steppes and northern mixed-grass prairie.** The measurement of bare ground and plant cover by image analysis reduces the subjectivity and bias that affects other vegetation-assessment methods and provides a permanent record that can be re-evaluated.

Experimental design: This hypothesis focuses on tool-development: finding or building, then testing, components and procedures for acquiring VLSA and related ground photography. Our current equipment and methods for acquisition of nadir aerial and ground digital images with sub-centimeter resolution are listed in Table 1. Bare ground is measured from air- and ground-images using a 100-point digital grid overlay and using VegMeasurement software (Dept. of Rangeland Resources, Oregon State University, Corvallis, OR). Aerial missions and correlated on-the-ground data collecting are planned annually with cooperators and unit scientists for rangelands of interest. The type of survey (BLM watershed or allotment, Nature Conservancy land, public and private pastures, research plots / pastures) and amount of ground-sampling varies. For example, a 2003 aerial survey of 12, 100 m X 400 m plots in a Unit research project, were sampled with 6 VLSA images and 8 ground plots per experimental unit. The 2003 cooperative monitoring effort for the USDA-ARS Sheep Experiment Station (cooperating with Dr. Steve Seefeldt) resulted in the acquisition of 400 VLSA images representing 11,000 ha of rangeland. Attendant ground-data collection used 20 GPS-located sites where 5, 0.5 m X 2 m quadrats were selected and sampled. The 2003 BLM watershed (~71,000 ha) monitoring effort required nearly 500 VLSA photographs of which 60 have paired 1 m X 1m ground plots. Images not used to compare ground and aerial data are needed for comparison with future surveys to test our ability to detect change over time, and for use in developing a GIS application and for comparison with space imagery. Cover values from ground and aerial assessments are being compared using paired t-tests and correlation analysis to determine the relationship between the corresponding data sets.

Table 1. Current equipment and methods for nadir aerial and ground digital images

Nadir aerial images	
Camera	11.1 megapixel Canon EOS-1DS digital camera interfaced with a 24 GB hard drive memory system (Image Labs Intl., Bozeman, MT)
Aircraft	Rans S12XL, 2-seat, ultralight-type airplane
Flight parameters	80 kph ground speed, 100 m above ground level (AGL
Navigation	Camera is automatically triggered for systematic, intermittent sampling of a single frame per target by a modified Track'Air aerial survey system using pre-programmed coordinates (Track'Air, Hengelo, The Netherlands). The software is interfaced with a cockpit display that directs the pilot to and over the target area.
Flight Plan	Didger II (Golden Software, Golden, CO) is used to extract GPS coordinates on a 0.5 mile grid from a digitized raster graphic of the study site. Coordinates are then entered into the flight plan creator in the Track'Air software.
Ground images	
Camera	Olympus E20 5.0 Megapixel with 35 mm Olympus lens mounted on a free-standing 2-m-high aluminum quadrat frame
Point sampling	A custom-built 10-laser point frame used to project 100 points / m^2 for bare-ground measurements from plots used for 2 m AGL

Geographic Information System (GIS) applications will be developed for rangeland managers with the private company Bitterroot Restoration, Inc., and for interfacing LandSat views of GPS-coordinated, high resolution views and VLSA imagery with the University of Wyoming, Wyoming Geographic Information Science Center (Drs. Ken Driese and Ramesh Sivanpillai). Upscaling work to assess the value of VLSA imagery for increasing the utility of space imagery has been initiated with a comparison of LandSat ETM+ and VLSA-derived bare-ground measurements in sagebrush. Dr. Ray Hunt will analyze Landsat Thematic Mapper images for Muddy and Cottonwood Creeks, Wyoming, (aerial surveys for BLM) to estimate fractional plant cover at 30-m pixel spatial resolution from vegetation indices (e.g., NDVI). We will then combine the fractional cover estimate from Dr. Hunt with data from VLSA photographs for the same GPS coordinates and test for a correlation between data sets. VLSA data will be used as ground truth for LandSat-derived data in the same way that ground photography is being used as ground truth for VLSA-derived measurements.

Hypothesis 2.1.b. **VLSA equipment and methods can be used to assess and monitor riparian woody plants within sagebrush steppe.** Aerial monitoring overcomes access problems of ground transportation and can be done more quickly, as accurately and less expensively than ground monitoring.

Experimental design: The study site is a large ranch 30 km northwest of Elko, Nevada. The ranch grazes more than 120,000 ha (81,000 ha BLM land and 39,000 ha owned by Barrick Corporation). Of particular interest on this ranch are 6 different stream and riparian areas within sagebrush steppe that have Lahontan cutthroat trout, a species listed as threatened. An agreement to improve the trout habitat has been made between Barrick, the BLM, Trout Unlimited and the U.S. Fish and Wildlife Service. Under new grazing plans that go into effect in 2004, some pastures will be excluded from any hot season grazing while other pastures will be grazed using a BLM protocol designed to enhance the fishery. Baseline information on riparian conditions is being collected during July 2003, using VLSA photography over 75% of the riparian system (1020 photographs for 80 linear km of stream). Concurrently, BLM will conduct on-the-ground assessments of 50 riparian sites covered in the aerial survey. Follow-up aerial surveys will be repeated every 4 years (i.e. 2007, 2011). The aerial surveys and statistical comparisons with ground-based measurements will be done with equipment and methods described above. The cost to the BLM for ground monitoring will be documented and compared to costs for VLSA monitoring.

Milestones for Objective 2.1: Test digital camera (2003); Evaluate accuracy of VLSA-derived cover measurements from digital camera (2004); Evaluate new VLSA imagery for the shortgrass prairie and if necessary develop and test alternate means of measuring or classifying cover for this system (2004); Begin development of GIS applications that facilitate the application of VLSA data to land management decision making (2004); Begin testing spatial analysis of patterns of bare ground (2005); Report on utility of VLSA for a variety of vegetation types (2005); Demonstrate the utility of VLSA monitoring to detect important vegetation change over time (2006); Interface VLSA data with LandSat data (upscaling) and determine if this extends the utility of current and historic LandSat data (2006)

Objective 2.2. Evaluate effectiveness of VLSA photography to monitor extent of invasive weeds in northern mixed-grass prairie.

Hypothesis 2.2. **VLSA photography can be used to determine stem density of the invasive weed dalmatian toadflax in northern mixed-grass prairie.** Although aerial and satellite imaging techniques can measure and map weed populations over extensive areas, these methods do not yield images with sufficient resolution to detect sparsely-distributed species or to measure populations below the patch scale. Greater resolution of VLSA photography will enable us to estimate population size of dalmatian toadflax more efficiently than with ground surveys.

Experimental design: The methodology for this study is principally described following hypothesis 1.3b. VLSA photography for the study will be acquired as described in Objective

2.1.a. Data collection and statistical analysis will include comparing on-the-ground counts with image-analysis (ERDAS) counts and using confidence limits calculated from the normal approximation to test for a significant difference in population counts. Correlation analysis will be used to determine the relationship between image-analysis counts and dalmatian toadflax phytomass harvested from within photographed areas.

Milestones for Objective 2.2: Fly study area (2004); Complete initial image analysis and evaluate results (2004); Repeat survey (2005, 2006)

Objective 2.3. Evaluate effectiveness of VLSA photography for monitoring changes in bare ground and leaf area index by plant functional group with modification of grazing management practices in shortgrass steppe. Evaluate effects of grazing-induced changes in vegetation composition, plant cover and bare ground on net ecosystem production, energy balance and evapotranspiration.

Hypothesis 2.3. **VLSA photography can accurately monitor changes in bare ground and relative plant cover of functional groups in shortgrass steppe.** Grazing-induced reductions in plant cover and increases in bare ground will result in reduced net ecosystem production and will alter the system energy balance, with increased system albedo and warmer canopy temperatures. This information will be utilized in future research to develop simulation models with inputs of VLSA photography, plant cover, species composition, bare ground and other site-specific climate data to predict the productivity and plant/soil water dynamics of VLSA photography-monitored sites.

Experimental design: Severe overgrazing and early spring, high intensity grazing treatments are described under hypotheses 1.2a and 1.2b in Objective 1.2 (see above). Briefly, grazing management strategies will be implemented in 2004 to modify the intensity (season-long severe overgrazing) and seasonality (spring) of grazing of shortgrass steppe in an attempt to modify habitat conditions (i.e., change vegetation states) for greater use by the mountain plover (*Charadrius montanus*), a potentially threatened bird species. Vegetation attributes including basal cover by species; bare ground, litter cover, dung cover, canopy cover by species and density (number of stems) by species will be measured in late-May (spring-grazed pastures) and late-June (overgrazed and control pastures) annually at a small scale ($0.1m^2$ plots). In addition, CO_2, water and energy fluxes will be monitored continuously throughout the experiment in spring-grazed and control pastures using Bowen ratio equipment (see Objective 1.2) to evaluate the capability of VLSA photography to document vegetation changes that relate to altered CO_2 and water dynamics. Surface albedo will also be determined periodically to determine if grazing causes increases that might be diagnostic of important state transitions (Li et al. 2000). VLSA photography of spring-grazed and control pastures will be acquired annually in late May, just after cattle are removed and concurrent with ground measurements. In addition, VLSA photography will be acquired in mid-July and early September to enable correlations to seasonal CO_2, water and energy fluxes. VLSA photography of the overgrazed summer pastures and control pastures will be acquired annually in late June, again concurrent with our ground measurements. Digitized raster graphics (DRGs) will be obtained for these pastures and flight lines and sampling intensity planned such that at least 10 VLSA images will be acquired for each upland and each lowland site in each pasture (not less than 20 images per pasture, including control pastures). Cover values from ground and aerial assessments are being compared using paired t-tests and correlation analysis to determine the relationship between the corresponding data sets.

Milestones for Objective 2.3: Obtain DRGs for pastures and plan flight lines (2003); Acquire VLSA data and complete first-year image analysis (2004); Acquire VLSA data annually for next 10 years; Acquire Bowen ratio and related data (2004, 2005 and 2006).

Contingencies for Objective 2: If the digital camera does not perform up to expectations, film will be used. If the services of pilot and airplane are lost, ground photography and analysis will continue while waiting for any needed purchases of equipment to proceed or arranging for an alternate contractor for flying services.

Management for Objective 2: D.T. Booth will manage all monitoring efforts pertaining to low altitude aerial and ground photography, in combination with computer image measurement techniques.

Necessary Collaborations for Objective 2: Collaboration with BLM (Wyoming State Office), Steven Seefelt (ARS, Dubois), Bob Budd (The Nature Conservancy) and Gregg Simonds (Rangeland Institute) on assessment areas. Collaboration with Doug Johnson on improvements to VegMeasurement software. Collaboration with Ray Hunt (ARS, Beltsville) on upscaling efforts, with Ramesh Sivanpillai and Ken Driese (University of Wyoming) on interfacing with LandSat and GIS applications, and with Bitterroot Restoration Inc. on development of the VLSA system and incorporating GIS tools customized for range managers.

Physical and Human Resources

Scientist office space is located at the High Plains Grasslands Research Station (HPGRS) in Cheyenne, Wyoming (D.T. Booth, J.D. Derner and G.E. Schuman) and the Crops Research Laboratory in Ft. Collins, Colorado (D.M. Blumenthal, J.A. Morgan and J.D. Reeder). These locations are approximately 85 km apart. The Crops Research Laboratory office and laboratory space is scheduled for renovation beginning in July 2003. The northern mixed-grass field site is located on the HPGRS (1,161 ha) and the shortgrass steppe field site is located on the Central Plains Experimental Range (6,273 ha). Nine technicians and two Cat. III support scientists are assigned to this project. Temporary staff (typically at GS-5 or below), students and a postdoc also will be available to assist with this project at varying levels. A soils laboratory, with a full array of analytical equipment, is located at HPGRS. Laboratory space, growth chamber equipment and four greenhouse bays are located at the Crops Research Lab. The greenhouse bays are tentatively scheduled for renovation in 2004/2005. The project has an extensive array of remote sensing and monitoring equipment.

Milestones and Expected Outcomes

Shown above by hypothesis.

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Past Accomplishments of D.Terrance Booth

Education:	B.S.	University of Nevada-Reno 1972
	M.S.	University of Nevada-Reno 1974
	Ph.D.	University of Wyoming 1987

Experience:	1974-1975	Soil Conservationist, USDA-SCS, Fallon, NV
	1975	Range Conservationist, USDA-SCS, Elko NV
	1975-1976	Agronomist, USDA-SCS, Plant Materials Center, Tucson, AZ
	1976-1979	Range Research Scientist, University of Idaho
	1979-present	Rangeland Scientist, USDA-ARS, Cheyenne, WY

Accomplishments:

Dr. Booth's research has focused on rangeland reclamation and seed physiology work with shrubs. His recent accomplishments in rangeland monitoring and remote sensing, however, include the introduction of the idea, and the camera-controlling hardware, for obtaining statistically adequate, large-scale, aerial photographic samples over extensive rangeland watersheds, in contrast to the convention of total photographic coverage. This work has utilized modern equivalents of earlier equipment, including a custom-built, aerial digital camera for high-speed, near-earth imaging to be compared with a modified 70 mm, high-speed, aerial film camera. These efforts are unique in developing effective rangeland monitoring procedures. These include: computerized, automatic equipment and sampling procedures for acquiring samples along aerial transects over extensive areas of rangeland, and demonstrating that plant cover measurements from aerial imagery could be as accurate as measurements made on the ground using conventional methods.

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Schuman, G.E., D.T. Booth and J.R. Cockrell. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. Journal of Range Management 51:223-230.

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Bai, Y., D.T. Booth and J.T. Romo. 1998. Developmental stages of winterfat germinants related to survival after freezing. Journal of Range Management 51:709-713.

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Bai, Y., S.P. Hardegree, D.T. Booth and E.E. Roos. 1999. Pericarp removal has little effect on sagebrush seeds. Journal of Range Management 52:384-386.

Hou, J.Q., J.T. Romo, Y. Bai and D.T. Booth. 1999. Desiccation tolerance in winterfat seeds and seedlings. Journal of Range Management 52:387-393.

Booth, D.T. and Y. Bai. 1999. Imbibition temperature affects on seedling vigor: In crops and shrubs. Journal of Range Management 52:534-538.

Booth, D.T. 1999. Imbibition temperatures affect bitterbrush seed dormancy and seedling vigor. Journal of Arid Environments 43:91-101.

Olson, R.A., J.K. Gores, D.T. Booth and G.E. Schuman. 2000. Suitability of shrub establishment on Wyoming mined lands reclaimed for wildlife habitat. Western North American Naturalist. 60:77-92.

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Booth, D.T. 2002. Seed longevity and seeding strategies affect sagebrush revegetation. Journal of Range Management 55:188-193.

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Hunt, E.R., J.H. Everitt, J.C. Ritchie, M.S Moran, D.T. Booth, and G.L. Anderson. 2003. Applications and Research Using Remote Sensing for Rangeland Management. Photogrammetric Engineering and Remote Sensing 69:675-694.

Bai, Y., D.T. Booth, and C.R. Tischler. Variation in germination and grain quality within rust resistant common wheat germplasm as affected by parental $C0_2$ conditions. Environmental and Experimental Botany (in press).

Booth, D.T. and P.T. Tueller. Rangeland monitoring using remote sensing. Journal of Arid Land Research and Management (in press).

Past Accomplishments of Dana M. Blumenthal

Education: B.S. Reed College 1992
M.S. University of Minnesota 2000
Ph.D. University of Minnesota 2002

Experience: 2002-present Ecologist, USDA-ARS, Fort Collins, CO

Accomplishments:

Dr. Blumenthal's research has focused on weed invasion of non-cropland ecosystems within agricultural landscapes. This work included theoretical studies of weed population dynamics, using a spatially explicit model of Canada thistle population dynamics to predict when weeds in field margins pose a threat to production within fields. More recently work focused on weed invasion of restored tallgrass prairie. He found that tallgrass prairie restoration reduces the abundance of an array of early successional weeds relative to cool season grass communities similar to those planted along roadsides. In a related set of experiments he tested the hypothesis that addition of high-carbon organic matter to the soil may induce microbial populations to immobilize available nitrogen, thereby favoring prairie species over weeds. The results showed that carbon addition can greatly facilitate prairie restoration, and provided the first experimental demonstration that nitrogen immobilization underlies the facilitation of ecological restoration by carbon addition.

Refereed Publications over Past 5 Years:

Blumenthal, D.M. and J.L. Jannink. 2000. A classification of collaborative management methods. Conservation Ecology 4:13.

Blumenthal, D. M. and N.R. Jordan. 2001. Weeds in field margins: a spatially explicit simulation analysis of *Cirsium arvense* population dynamics. Weed Science 49:509-519.

Blumenthal, D.M., N.R. Jordan and E.L. Svenson. 2003. Weed control as a rationale for restoration: the example of tallgrass prairie. Conservation Ecology 7:6.

Blumenthal, D.M., N.R. Jordan and M.P. Russelle. Soil carbon addition controls weeds and facilitates prairie restoration. Ecological Applications (in press).

Past Accomplishments of Justin D. Derner, Lead Scientist

Education:	B.S.	University of Nebraska-Lincoln 1991
	M.S.	Oklahoma State University 1993
	Ph.D.	Texas A&M University 1996

Experience:	1996-1997	Postdoctoral Research Associate, Texas A&M University
	1998-2002	Rangeland Scientist, USDA-ARS, Temple, TX
	2002-present	Rangeland Scientist, USDA-ARS, Cheyenne, WY

Accomplishments:

Dr. Derner has conducted research on impacts of predicted increases in atmospheric carbon dioxide (CO_2) concentration on root structure and function of rangeland plants, effects of predicted shifts in seasonality and distribution of precipitation on rangeland ecosystem structure and function, and influences of plant morphology, grazing history and climate on carbon and nitrogen storage in soils of mesic and semi-arid rangelands. His research has demonstrated that the indirect effect of CO_2 enrichment on conservation of soil water in rangelands may be as important as direct photosynthetic response effects in the enhancement of root growth of warm-season grasses with elevated CO_2, tallgrass prairie vegetation is not appreciably modified by changes in seasonality and distribution of precipitation, and substantial carbon sequestration is possible in rangelands that have experienced or are currently experiencing vegetation change. Dr. Derner was recognized by the Society of Range Management as the Outstanding Young Range Professional in 2002.

Refereed Publications over the past 5 years:

Derner, J.D. and D.D. Briske. 1998. An isotopic (^{15}N) assessment of intraclonal function in C_4, perennial grasses: Ramet interdependence, independence or both? Journal of Ecology 86:305-314.

Derner, J.D. and D.D. Briske. 1999. Intraclonal regulation in a perennial, caespitose grass: a field evaluation of above- and belowground resource availability. Journal of Ecology 87:737-747.

Derner, J.D. and D.D. Briske. 1999. Does a tradeoff exist between morphological and physiological root plasticity? A comparison of grass growth forms. Acta Oecologia 20:519-526.

Derner, J.D. and D.D. Briske. 2001. Below-ground carbon and nitrogen accumulation in perennial grasses: A comparison of caespitose and rhizomatous growth forms. Plant and Soil 237:117-127.

Derner, J.D. and X.B. Wu. 2001. Light distribution in mesic grasslands: spatial patterns and temporal dynamics. Applied Vegetation Science 4:189-196.

Derner, J.D., H.W. Polley, H.B. Johnson and C.R. Tischler. 2001. Root system responses of C_4 grass seedlings to CO_2 and soil water. Plant and Soil 231:97-104.

Polley, H.W., C.R. Tischler, H.B. Johnson and J.D. Derner. 2002. Growth rate and survivorship of drought: CO_2 effects on the presumed tradeoff in seedlings of five woody legumes. Tree Physiology 22:383-391.

Polley, H.W., H.B. Johnson and J.D. Derner. 2002. Soil- and plant-water dynamics in a C_3/C_4 grassland exposed to a subambient to superambient CO_2 gradient. Global Change Biology 8:1118-1129.

Derner, J.D., H.B. Johnson, B.A. Kimball, P.J. Pinter Jr., H.W. Polley, C.R. Tischler, T.W. Boutton, R.L. LaMorte, G.W. Wall, N.R. Adam, S.W. Leavitt, M.J. Ottman, A.D. Matthias and T.J. Brooks. 2003. Above- and belowground responses of C_3-C_4 species mixtures to elevated CO_2 and soil water availability. Global Change Biology 9:452-460.

Polley, H.W., B. Wilsey and J.D. Derner. 2003. Do species evenness and plant diversity influence the magnitude of selection and complimentary effects in annual species mixtures? Ecology Letters 6:248-256.

Derner, J.D., C.R. Tischler, H.W. Polley and H.B. Johnson. Intergenerational above- and belowground responses of spring wheat (*Triticum aestivum*) to elevated CO_2. Basic and Applied Ecology (in press).

Derner, J.D., H.W. Polley, H.B. Johnson and C.R. Tischler. Structural attributes of *Schizachyrium scoparium* in restored Texas Blackland prairies. Restoration Ecology (in press).

Polley, H.W., H.B. Johnson and J.D. Derner. Increasing CO_2 from subambient to superambient concentrations alters species composition and increases aboveground biomass in a C_3/C_4 grassland. New Phytologist (in press).

Past Accomplishments of Jack A. Morgan

Education:	B.S.	New Mexico State University 1975
	M.S.	University of Georgia1978
	Ph.D.	University of Georgia 1981

Experience	1981-1993	Research Agronomist, USDA-ARS, Ft. Collins, CO
	1993-1998	Plant Physiologist, USDA-ARS, Ft. Collins, CO
	1998-present	Research Leader, USDA-ARS Rangeland Resources Research Unit, Ft. Collins/Cheyenne

Accomplishments:

Dr. Morgan's research accomplishments have been primarily in the field of photosynthesis, including detailed studies of leaf gas exchange investigating basic physiological mechanisms, but have also included whole-plant and field-based studies in which microclimate and nutritional effects on gas exchange of CO_2 and other trace gases were assessed. His early work in ARS evaluated plant water relations in winter wheat for their usefulness in improving plant germplasm. In the past ten years his research focus has been in global change biology, where he has evaluated the consequences of rising atmospheric CO_2 concentrations on the ecology of Great Plains grasslands. He and his colleagues have determined that while elevated atmospheric CO_2 concentrations will likely enhance forage production and improve water relations in grasslands, higher CO_2 will also lead to lower forage quality and changes in grassland plant communities as CO_2 favors some species over others. His present research is directed towards developing sustainable rangeland management practices that account for on-going global changes, and lessen greenhouse gas emissions of rangelands.

Refereed Publications over Past 5 Years:

LeCain, D.R. and J.A. Morgan. 1998. Growth, photosynthesis, leaf nitrogen and carbohydrate concentrations in NAD-ME and NAD-ME C_4 grasses grown in elevated CO_2. Physiologia Plantarum 102:297-306.

Hunt, H.W., J.A. Morgan and J.J. Read. 1998. Simulating growth and root-shoot partitioning in prairie grasses under elevated atmospheric CO_2 and water stress. Annals of Botany 81:489-501.

Morgan, J.A., D.R. LeCain, J.J. Read, H.W. Hunt and W.G. Knight. 1998. Photosynthetic pathway and ontogeny affect water relations and the impact of CO_2 on *Bouteloua gracilis* (C_4) and *Pascopyrum smithii* (C_3). Oecologia 114: 483-493.

McMaster, G.S., D.R. LeCain, J.A. Morgan, L. Aiguo and D.L Hendrix. 1999. Elevated CO_2 increases wheat CER, leaf and tiller development, and shoot and root growth. Journal of Agronomy and Crop Science 183:119-128.

Skinner, R.H., J.A. Morgan and J.D. Hanson. 1999. Carbon and nitrogen reserve remobilization following defoliation: Nitrogen and elevated CO_2 effects. Crop Science 39:1749-1756.

LeCain, D.R., J.A. Morgan, G.E. Schuman, J.D. Reeder and R.H. Hart. 2000. Carbon exchange rates in grazed and ungrazed pastures of Wyoming. Journal of Range Management 53:199-206.

Campbell, B.D., D.M. Stafford Smith, A.J. Ash, J. Fuhrer, R.M. Gifford, P. Hiernaux, S.M. Howden, M.B. Jones, J.A. Ludwig, R. Manderscheid, J.A. Morgan, P.C.D. Newton, J. Nosberger, C.E. Owensby, J.F. Soussana, Z. Tuba and C. ZuoZhong. 2000. A synthesis of recent global change research on pasture and rangeland production: reduced uncertainties and their management implications. Agriculture, Ecosystems and the Environment 82:39-55.

Morgan, J.A., R.H. Skinner and J.D. Hanson. 2001. Nitrogen and CO_2 affect regrowth and biomass partitioning differently in forages of three functional groups. Crop Science 41:78-86.

Schuman, G.E., D.R. LeCain, J.D. Reeder and J.A. Morgan. 2001. Carbon dynamics and sequestration of a mixed-grass prairie as influenced by grazing. *In* R.Lal and K. McSweeney (ed.) Soil carbon sequestration and the greenhouse effect. Soil Science Society of America Special Publication No. 57, pp 67-75, Soil Science Society of America, Madison, WI.

Morgan J.A., D.R. LeCain, A.R. Mosier and D.G. Milchunas. 2001. Elevated CO_2 enhances water relations and productivity and affects gas exchange in C_3 and C_4 grasses of the Colorado Shortgrass Steppe. Global Change Biology 7:451-466.

LeCain, D.R., J.A. Morgan, G.E. Schuman, J.D. Reeder and R.H. Hart. 2002. Carbon exchange rates and species composition of grazed pastures and exclosures in the shortgrass steppe of Colorado. Agriculture, Ecosystems and Environment 93:421-435.

Gill, R.A., R.H. Kelly, W.J. Parton, K.A. Day, R.B. Jackson, J.A. Morgan, J.M.O. Scurlock, L.L. Tieszen, J. van de Castle, D.S. Ojima and X.S. Zhang. 2002. Using simple environmental variables to estimate belowground productivity in grasslands. Global Ecology and Biogeography 11:79-86.

Mosier, A.R., J.A. Morgan, J.Y. King, D. LeCain and D.G. Milchunas. 2002. Soil-atmosphere exchange of CH_4, CO_2, NO_x, and N_2O in the Colorado Shortgrass Steppe under elevated CO_2. Plant and Soil 240:201-211.

Morgan, J.A. 2002. Looking beneath the surface. Science 298:1903-1904.

LeCain, D.R., J.A. Morgan, A.R. Mosier and J.A. Nelson. 2003. Soil and plant water relations, not photosynthetic pathway, primarily influence photosynthetic responses in a semi-arid ecosystem under elevated CO_2. Annals of Botany 92:41-52.

Mosier, A.R., E. Pendall and J.A. Morgan. 2003. Soil-atmosphere exchange of CH_4, CO_2, NO_x, and N_2O in the Colorado Shortgrass steppe following five years of elevated CO_2 and N fertilization. Atmospheric Chemistry and Physics Discussions 3:2691-2706.

King, J.Y., A.R. Mosier, J.A. Morgan, D.R. LeCain, D.G. Milchunas and W.J. Parton. Plant nitrogen dynamics in shortgrass steppe under elevated atmospheric CO_2. Ecosystems (in press).

Ferretti, D.F., E. Pendall, J.A. Morgan, J.A. Nelson, D.R. LeCain and A.R. Mosier. Partitioning evapotranspiration fluxes from a Colorado grassland using stable isotopes: seasonal variations and implication for elevated atmospheric CO_2. Plant and Soil (in press).

Pendall, E., S. Del Grosso, J.Y. King, D.R. LeCain, D.G. Milchunas, J.A. Morgan, A.R. Mosier, D.S. Ojima, W.A. Parton, P.P. Tans and J.W.C. White. 2003. Elevated atmospheric CO_2 effects and soil water feedbacks on soil respiration components in a Colorado grassland. Global Biogeochemical Cycles (in press).

Morgan, J.A., A.R. Mosier, D.G. Milchunas, D.R. LeCain, J.A. Nelson and W.J. Parton. CO_2 enhances productivity of the shortgrass steppe, alters species composition and reduces forage digestibility. Ecological Applications (in press).

Nelson, J.A., J.A. Morgan, D.R. LeCain, A.R. Mosier, D.G. Milchunas and W.J. Parton. Elevated CO_2 increases soil moisture and enhances plant water relations in a long-term field study in the semi-arid shortgrass steppe of Northern Colorado. Plant and Soil (in press).

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Past Accomplishments of Jean D. Reeder

Education: B.S. University of Nebraska-Lincoln 1973
M.S. Colorado State University 1975
Ph.D. Colorado State University 1981

Experience: 1975-present Soil Scientist, USDA-ARS, Fort Collins, CO

Accomplishments

Dr. Reeder has conducted studies on carbon and nitrogen cycling in mined lands, native rangeland ecosystems, and reseeded CRP grasslands. She worked closely with other soil scientists to demonstrate that the rate of soil organic matter (SOM) recovery following the reestablishment of grasses on CRP lands is dependent on soil texture, and that the labile fractions of SOM recover more rapidly than total SOM. Other collaborative work demonstrated that grazing strategies that push mixed-grass and short-grass ecosystems to a blue grama-dominated plant community result in increased organic C sequestration in the soil profile. Dr. Reeder is recognized for establishing that increases in inorganic soil C are twice the magnitude of the increases in organic C resulting from grazing-induced shifts to a blue grama-dominated plant community.

Refereed Publications over the past 5 years:

Herrick, J.E., M.A. Weltz, J.D. Reeder, G.E. Schuman and J.R. Simanton. 1998. Rangeland soil erosion and soil quality: role of soil resistance, resilience and disturbance regimes. pp. 209-233. In: Rattan Lal (ed). Soil Erosion and Soil Quality. CRC Press LLC, Baca Raton, FL.

Reeder, J.D., G.E. Schuman and R.A. Bowman. 1998. Soil C and N changes on conservation reserve program (CRP) lands in the Central Great Plains, USA. Soil and Tillage Research 47:339-349.

Schuman, G.E., J.D. Reeder, J.T. Manley, R.H. Hart and W.A. Manley. 1999. Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. Ecological Applications 9:65-71.

LeCain, D.L., J.A. Morgan, G.E. Schuman, J.D. Reeder and R.H. Hart. 2000. Carbon exchange rates in grazed and ungrazed pastures of Wyoming. Journal of Range Management 53:199-206.

Reeder, J.D., C.D. Franks and D.G. Milchunas. 2001. Root biomass and microbial processes. pp. 139-166. In: R.Lal et al. (ed.) The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. Lewis Publishers, Boca Raton, Florida.

Reeder, J.D., and G.E. Schuman. 2001. Effects of grazing on carbon sequestration. pp. 75-78. McGraw-Hill 2001 Yearbook of Science & Technology.

Schuman, G.E., D.R. LeCain, J.D. Reeder and J.A. Morgan. 2001. Carbon dynamics and sequestration of a mixed-grass prairie as influenced by grazing. pp. 67-75. In: R. Lal (ed.) Soil Carbon Sequestration and the Greenhouse Effect. Soil Science Society of America Special Publication No.57, Soil Science Society of America, Madison, WI.

LeCain, D.R., J.A. Morgan, G.E. Schuman, J.D. Reeder and R.H. Hart. 2002. Carbon exchange and species composition of grazed and ungrazed pastures in the shortgrass steppe of Colorado. Agriculture, Ecosystems and Environment 93:421-435.

Reeder, J.D. and G.E. Schuman. 2002. Influence of livestock grazing on C sequestration in semi-arid mixed-grass and short-grass rangelands. Environmental Pollution 116:457-463.

Bowman, R.A., J.D. Reeder and B.J. Weinhold. 2002. Quantifying laboratory and field variability to assess potential for carbon sequestration. Communications in Soil Science and Plant Analyses 33:1629-1642.

Wheeler, M.A., M.J. Trlica, G. W. Frasier and J.D. Reeder. 2002. Seasonal grazing affects soil physical properties of a montane riparian community. Journal of Range Management 55:49-56.

Reeder, J.D., G.E. Schuman, J.A. Morgan and D.R. LeCain. Response of organic and inorganic carbon and nitrogen to long-term grazing of the short-grass steppe. Environmental Management (in press).

Past Accomplishments of Gerald E. Schuman

Education:	B.S.	University of Wyoming 1966
	M.S.	University of Nevada-Reno 1969
	Ph.D.	University of Nebraska-Lincoln 1974

Experience:	1966-1969	Soil Scientist, USDA-ARS, Reno, NV
	1969-1975	Soil Scientist, USDA-ARS, Lincoln, NE
	1975-1976	Soil Scientist, USDA-ARS, Cheyenne, WY
	1976-1991	Research Leader, Soil Scientist, USDA-ARS, Mined Land Reclamation and Rangeland Management Research Unit, Cheyenne, WY
	1991-1998	Research Leader, Soil Scientist, USDA-ARS, Rangeland Resources Research Unit, Cheyenne WY/Fort Collins, CO
	1998-present	Soil Scientist, USDA-ARS, Cheyenne, WY

Accomplishments:

Dr. Schuman's research has focused on the effects of management (grazing and vegetation) on soil carbon cycling and sequestration in rangelands and degraded croplands. His research has demonstrated the importance of rangeland management on carbon sequestration. The research has demonstrated that good grazing management will result in greater carbon sequestration than observed under non-grazed rangelands. He has also found that interseeding of *Medicago sativa* ssp. f*alcata* into native rangelands will greatly enhance carbon sequestration, forage quality and forage production. Addition of a legume to the native rangelands greatly enhances the soil quality through enhanced levels of nitrogen and soil organic matter, and has not significantly affected emissions of nitrous oxide from the ecosystem.

Refereed Publications over Past 5 Years:

Herrick, J.E., M.A. Weltz, J.D. Reeder, G.E. Schuman and J.R. Simanton. 1998. Rangeland soil erosion and soil quality: role of soil resistance, resilience and disturbance regimes. pp. 209-233. In: Rattan Lal (ed). Soil Erosion and Soil Quality. CRC Press LLC, Boca Raton, Florida.

Reeder, J.D., G.E. Schuman and R.A. Bowman. 1998. Soil C and N changes on conservation reserve program (CRP) lands in the Central Great Plains, USA. Soil and Tillage Research 47:339-349.

Stahl, P.D., G.E. Schuman, S.M. Frost and S.E. Williams. 1998. Interaction of arbuscular mycorrhiza and seedling age on water stress tolerance of *Artemisia tridentata* ssp. *wyomingensis*. Soil Science Society of America Journal 62:1309-1313.

Schuman, G.E., J.D. Reeder, J.T. Manley, R.H. Hart and W.A. Manley. 1999. Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. Ecological Applications 9:65-71.

LeCain, D.R., J.A. Morgan, G.E. Schuman, J.D. Reeder, and R.H. Hart. 2000. Carbon exchange rates in grazed and ungrazed pastures of Wyoming. Journal of Range Management 53:199-206.

Schuman, G.E., J.E. Herrick and H.H. Janzen. 2001. The dynamics of soil carbon in rangelands. Chapter 11, pp. 267-290. In: R.F. Follett, J.M. Kimble, and R. Lal (eds.) The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. Lewis Publishers, Boca Raton, FL.

Schuman, G.E., D.R. LeCain, J.D. Reeder and J.A. Morgan. 2001. Carbon dynamics and sequestration of a mixed-grass prairie as influenced by grazing. pp. 67-75. In: R. Lal (ed.) Soil Carbon Sequestration and the Greenhouse Effect. Soil Science Society of America Special Publication No.57, Soil Science Society of America, Madison, WI.

LeCain, D.R., J.A. Morgan, G.E. Schuman, J.D. Reeder and R.H. Hart. 2002. Carbon exchange and species composition of grazed and ungrazed pastures in the shortgrass steppe of Colorado. Agriculture, Ecosystems and Environment 93:421-435.

Schuman, G.E., H.H. Janzen and J.E. Herrick. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. Environmental Pollution 116:391-396.

Skinner, R.H., J.D. Hanson, G.L. Hutchinson and G.E. Schuman. 2002. Response of C_3 and C_4 grasses to supplemental summer precipitation. Journal of Range Management 55:517-522.

Reeder, J.D., G.E. Schuman, J.A. Morgan and D.R. LeCain. Response of organic and inorganic carbon and nitrogen to long-term grazing of the short-grass steppe. Environmental Management (in press).

Mortenson, M.C., G.E. Schuman and L.J. Ingram. Carbon sequestration in rangelands interseeded with yellow-flowering alfalfa (*Medicago sativa* ssp. *falcata*). Environmental Management (In press).

Miyamoto, D.L., R.A. Olson and G.E. Schuman. Long-term effects of mechanical renovation of a mixed-grass prairie: I. Plant production. Arid Lands Research and Management (In press).

Miyamoto, D.L., G.E. Schuman and R.A. Olson. Long-term effects of mechanical renovation of a mixed-grass prairie: II. Carbon and nitrogen balance. Arid Lands Research and Management (In press).

Health, Safety, and Other Issues of Concern Statement

Animal Care

Livestock used in these studies are privately owned by 8A Hay and Cattle Company (HPGRS) and the members of Crow Valley Livestock Association (CPER). The grazing treatments are monitored and supervised by the ARS Animal Care and Use Committee for each field site location. All regulations concerning care and use of livestock in research will be followed. The animal handling facilities at CPER are being updated (scheduled for September 2003)

Endangered Species

Research will not be conducted in areas where endangered plants and animals reside.

Environmental Impact Statement

This research project has been examined for potential impacts on the environment as has been found to be categorically excluded under the ARS National Environmental Policy Act.

Human Study Procedure

Not relevant.

Laboratory Hazards

Hazardous materials in the proposed research include strong bases and acids. These materials will be handled with protective clothing in a fume hood and all pipetting will be done mechanically. Hazard assessments and safety protocols have been developed for all laboratory operations. Safety glasses and goggles are worn by all persons in the labs and eyewash stations and showers are available. All ARS Safety policies and procedures are followed.

Occupational Safety and Health

Appropriate Occupational Health Maintenance physical examinations are conducted on a yearly basis for all employees subjected to any condition relating to health and well-being issues. Laboratory and field safety manuals and operating procedures are in place. An appropriate Chemical Safety and Hygiene Plan is in place and employees are properly trained.

Recombinant DNA Procedures

Not relevant.

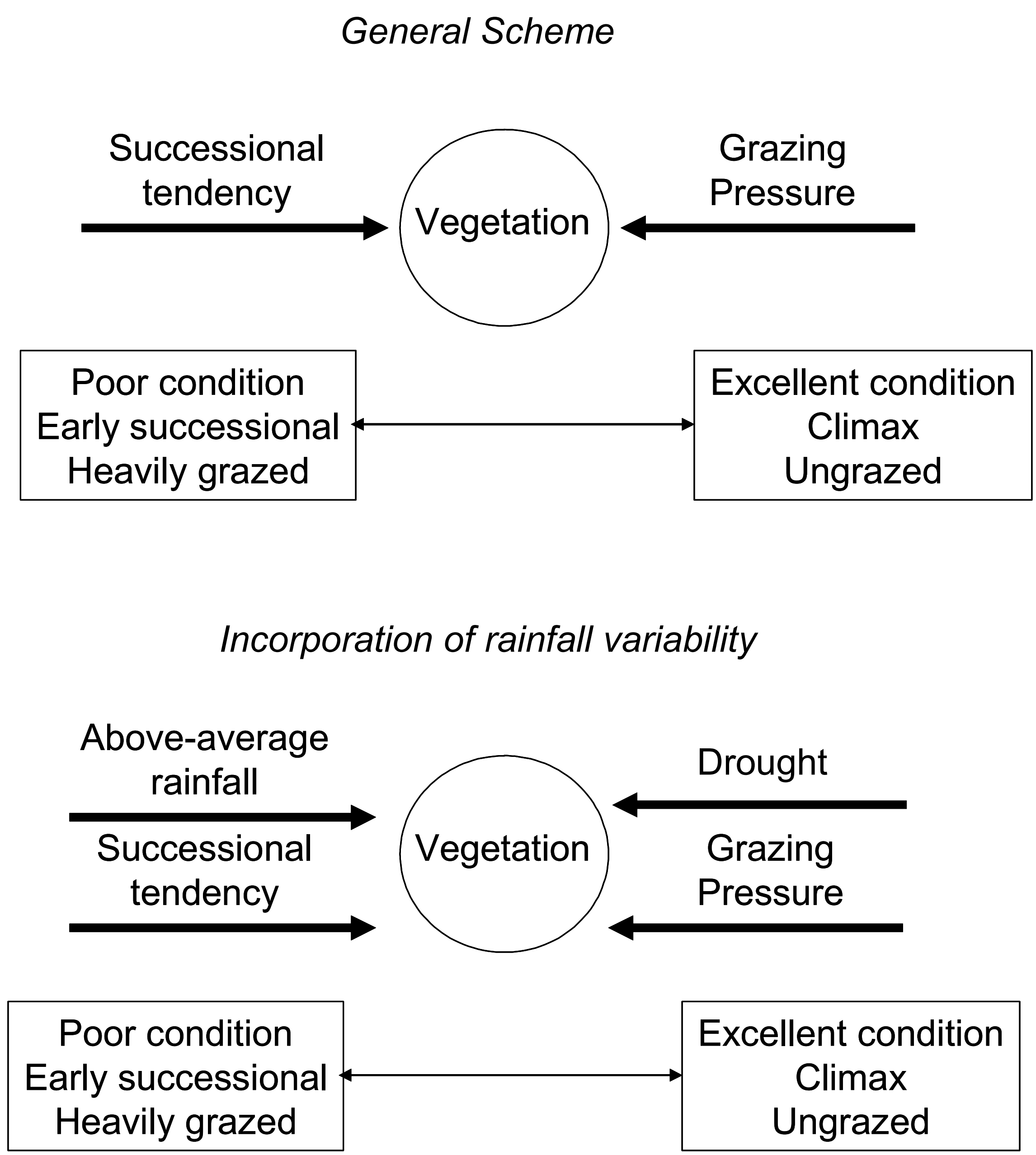

Figure 1. Range succession/retrogression model (from Westoby et al. 1989).

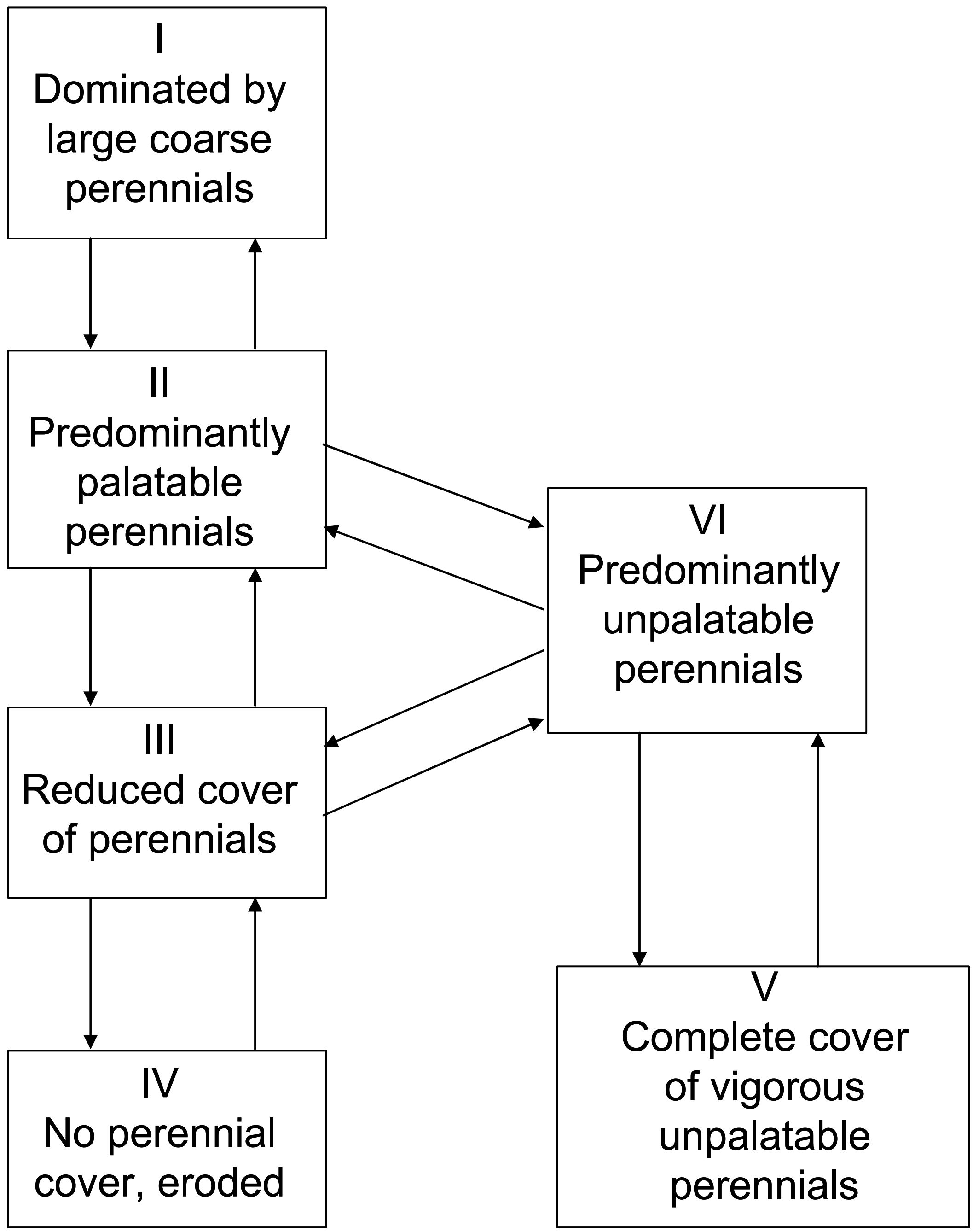

Figure 2. State-and-transition model for a tall grassveld in South Africa (from Westoby et. al 1989).

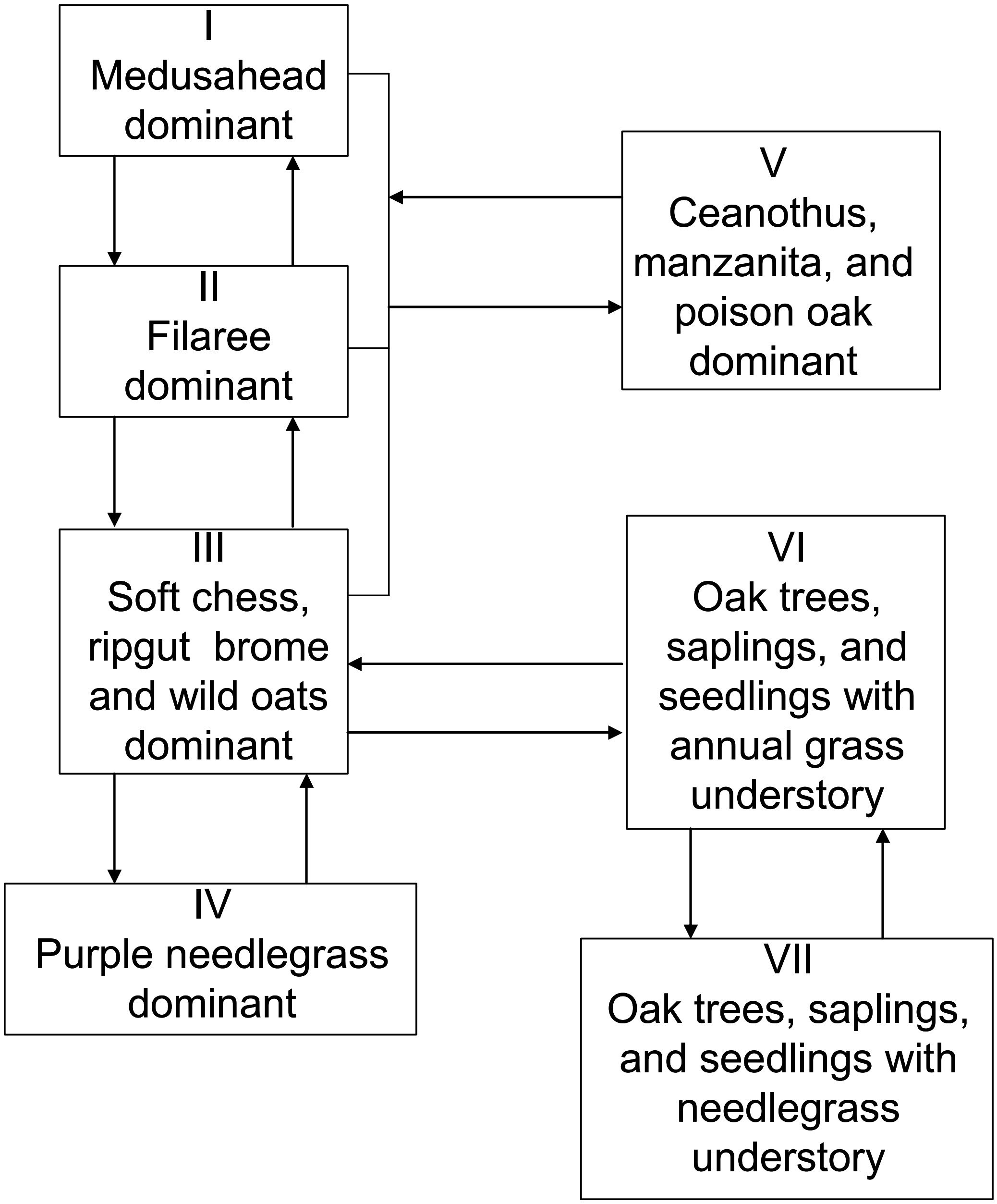

Figure 3. State-and-transition model for a California annual grassland (from George et al. 1992).

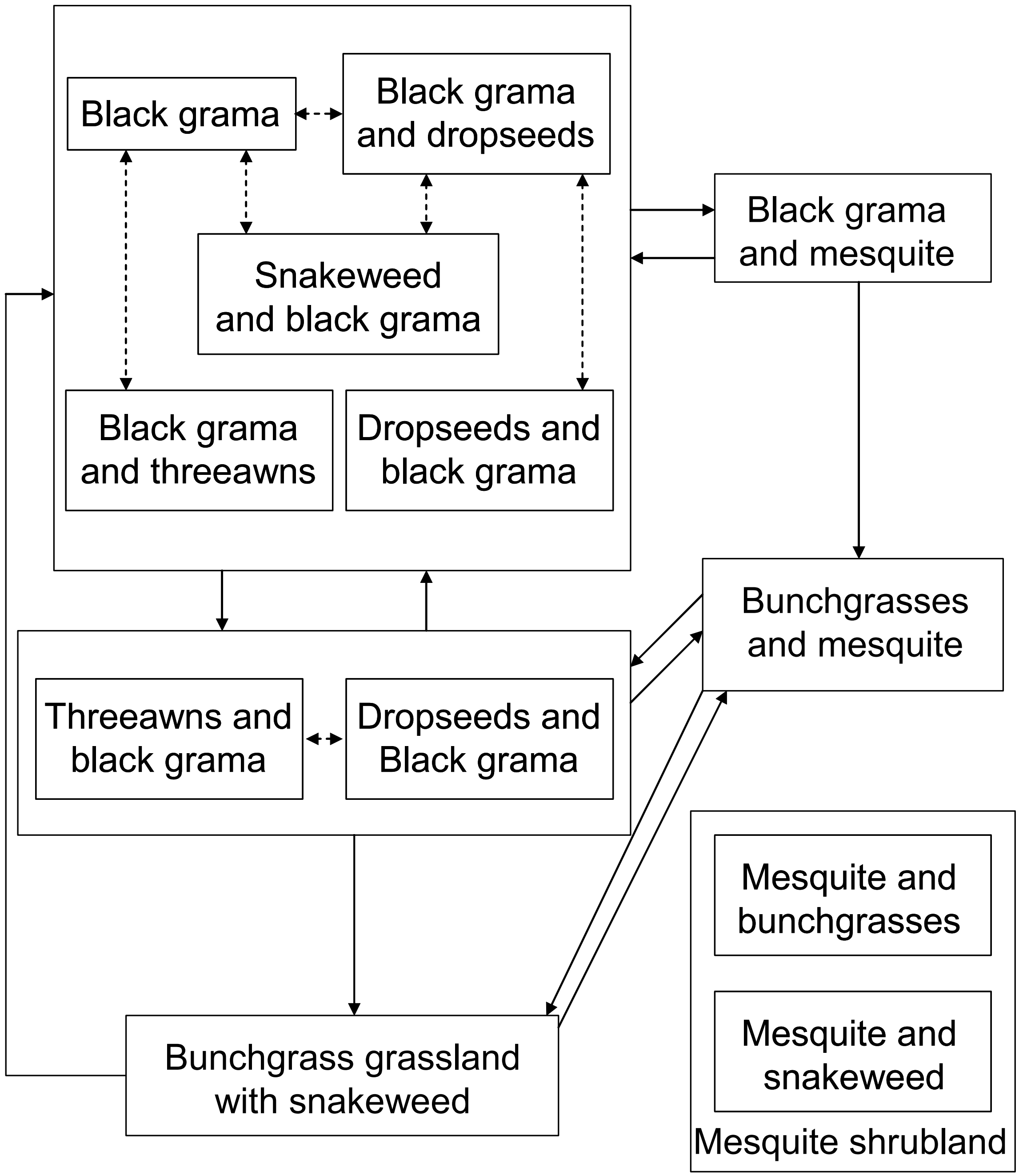

Figure 4. State-and-transition model for grassland/shrublands of southern New Mexico (from Bestelmeyer et al. 2003).

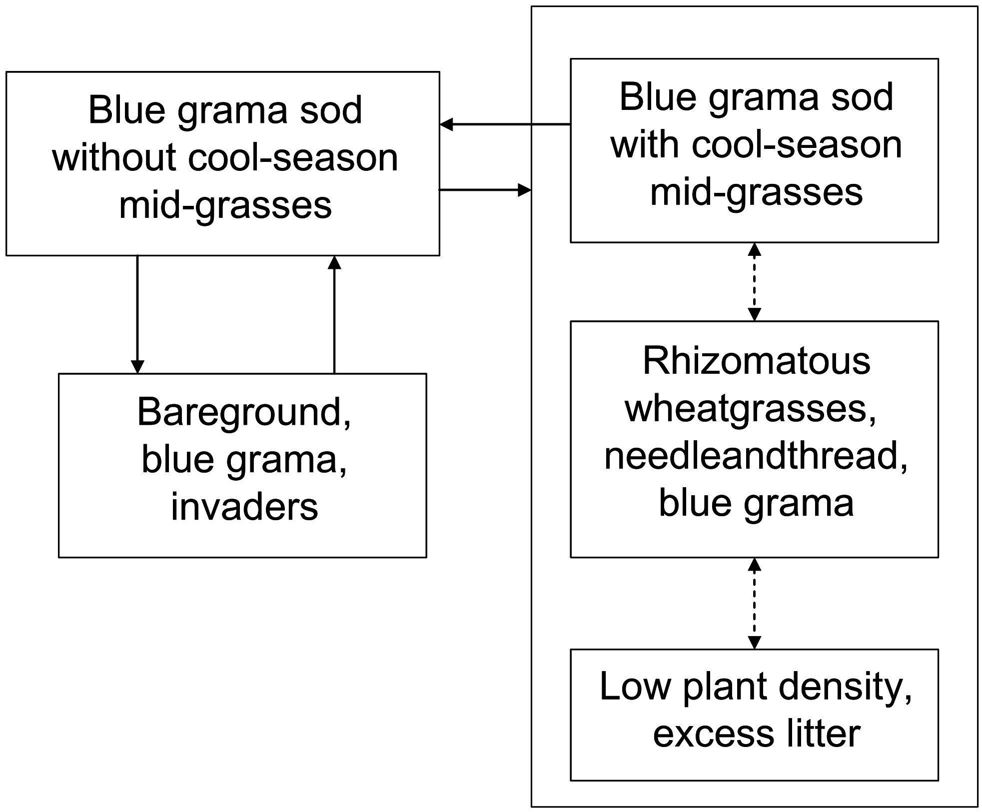

Figure 5. State-and-transition model for northern mixed-grass prairie, MLRA 67 - Loamy 12-17 inch precipitation (from NRCS).

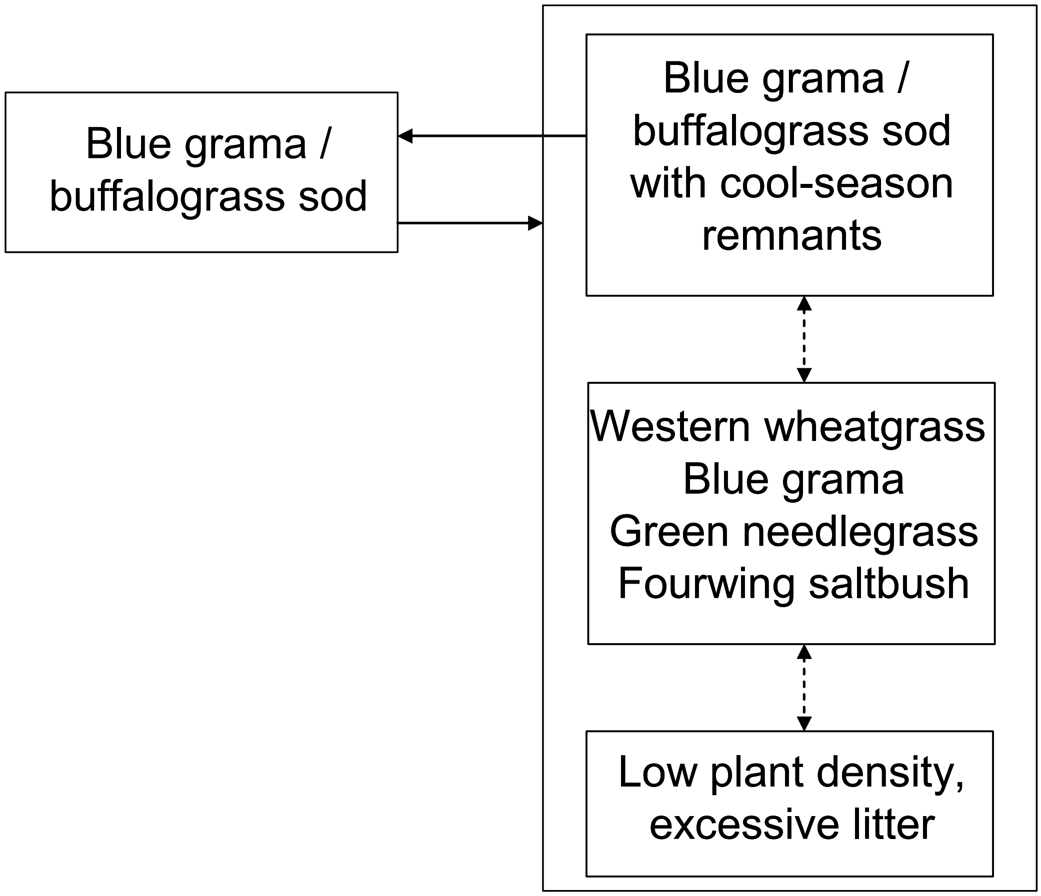

Figure 6. Partial state-and-transition model for shortgrass steppe, MLRA 67B - Loamy (from NRCS).

Colorado State University
Knowledge to Go Places

Department of Forest, Rangeland & Watershed Stewardship
Fort Collins, Colorado 80523-1478 USA
Telephone (970) 491-6677
FAX (970) 491-2339
http://www.cnr.colostate.edu/FRWS/

July 9, 2003

This letter documents the collaboration I have with the USDA – ARS Rangeland Resources Research Unit (RRRU) regarding grazing experiments in shortgrass steppe at the Central Plains Experimental Range (CPER). I have been conducting rangeland research on the shortgrass steppe at the CPER for the past thirty years, I have been past lead PI for the Shortgrass Steppe Long-term Ecological Research (SGS-LTER) group, and I am internationally recognized as a leading expert regarding grassland ecology in semi-arid environments. During the time I have worked at the CPER, I have had prior collaborative research with the RRRU and for the period 1982-1996 I had a RRRU co-PI on the SGS-LTER project. W. A. Laycock and I collaborated on a white-grub disturbance project at the CPER that resulted in a refereed journal article (see list). A few key recent papers are provided below which describe my expertise in rangeland/grassland ecology:

Coffin, D.P., W. A. Laycock and W. K. Lauenroth. 1998. Disturbance intensity and above-and belowground herbivory effects on long-term (14-yr) recovery of a semiarid grassland. Plant Ecology 139:221-233.
Aguiar, M.R., W.K. Lauenroth and D.P.C. Peters. 2001. Intensity of intra- and interspecific competition in coexisting shortgrass species. Journal of Ecology 89:40-47.
Adler, P.B., D.A. Raff and W.K. Lauenroth. 2001. Effects of grazing on the spatial heterogeneity of vegetation. Oecologia 128:465-479.
Adler, P.B. and W.K. Lauenroth. 2001. Livestock exclusion increases the spatial heterogeneity of vegetation in the shortgrass steppe. Applied Vegetation Science 3:213-222.
Aguiar, M.R. and W.K. Lauenroth. 2001. Local and regional differences in abundance of co-dominant grasses in the shortgrass steppe: a modeling analysis of potential causes. Plant Ecology 156:161-171.
Dodd, M.B., W.K. Lauenroth and I.C. Burke. 2002. Associations between vegetation patterns and soil texture in the shortgrass steppe. Plant Ecology 158:127-137.

For this Project Plan, I will be specifically collaborating on Objective 1.3 which addresses grazing management strategies that influence the abundance and diversity of desired plant species through changes in the intensity and seasonality of grazing. This collaborative project with RRRU scientists is planned to begin in 2004. We have recently concluded the collection of baseline vegetation data. This effort included technical staff from the RRRU, my research group, and the SGS-LTER group. For this collaborative research project, I have committed to 1) provide scientific input into the experimental design and methodology, 2) provide technical staff to assist in the annual vegetation data collection efforts and, if needed, to assist in data entry and quality control, 3) participate in the summarization of data and preparation/review of scientific manuscripts, and oral/poster presentations. In addition, I will be the lead PI on a USDA-NRI Managed Ecosystem grant proposal this fall that will seek additional funding for this collaborative research effort to provide opportunities for graduate students on this project.

I am excited about this collaborative research effort and look forward to a highly productive project that yields valuable information that is pertinent to producers, land managers, the scientific community and governmental entities.

Sincerely,

Dr. William K. Lauenroth
Professor
Department of Forest, Range and Watershed Stewardship
Colorado State University

Colorado State University

Natural Resource
Ecology Laboratory
Fort Collins, Colorado 80523-1499 U.S.A.
FAX: (970) 491-1965

July 8, 2003

Dr. Dana Blumenthal
USDA-ARS Rangland Resources Research
Unit, Crops Research Laboratory
1701 Center Ave.
Fort Collins, CO, 80526

Dear Dana,

I am writing in support of your CRIS application that will involve collaboration between our two research groups in the study of weed invasion processes as affected by a suite of climate change scenarios. The collaboration will involve establishing "weed" plots within my existing NIGEC study of coupled changes in winter and summer climate on Mixedgrass Prairie ecosystem and organismic function. We will provide plot space in areas where snow cover is deep in winter (snow fences) and in study areas where snow cover is ambient in winter. These experimental sites have been established in 2003 and during the winter of 2002-2003 we had effective accumulation of snow cover ensuring divergent soil water conditions in spring and early summer resulting from this winter-time experimental manipulation.

This study of ecosystem and organismic function under coupled changes in winter and summer climate contributes to my array of field studies examining rangeland responses to changes in climate supported by NSF and DOE (Jones et al. 1998, Walker et al. 1999, Welker et al. 1999, Welker et al. 2000). Several of these studies have been on-going for >10 years and we are increasing recognizing the importance of changes in winter conditions as dominating the nature and dynamics of growing season processes. I am anticipating that the success of rangeland weeds, in term of establishment and growth will greatly depend on the previous winter snow conditions as it controls early season soil moisture.

The necessary facilities are currently in place and available for your study and I look forward to working with you and your research team.

Sincerely,

Jeffrey M. Welker

Dr. Jeffrey M. Welker
Sr. Research Scientitst
NREL
Faculty, Graduate Degree Program
In Ecology, CSU

Bitterroot Restoration
INCORPORATED

July 18, 2003

To: Dr. Jack Morgan, Research Leader, USDA HGRS

From: Tim Meikle, Director of Research and Development, Bitterroot Restoration, Inc.

Subject: Collaboration on the use of the very large-scale aerial (VLSA) imagery for monitoring rangelands

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Dr. Jack Morgan
USDA ARS
High Plains Grasslands Research Station
8408 Hildreth Road
Cheyenne, WY
82009

Dr. Morgan:

I am writing this statement of collaboration at the request of Terry Booth, PhD of the High Grasslands Research Station (HPGRS) on the development of an integrated remote sensing and Geographical Information System (GIS). I have personally worked with Dr. Booth on a previous research project and we have developed a strong working relationship. I am very excited about further collaboration with the Range Research Group regarding their Very Large-Scale Aerial Imagery (VLSA) technology.

Regarding myself, I became a consulting restoration ecologist with BRI in 1994 after receiving my Master of Science degree in Restoration Ecology from the University of Wisconsin-Madison. Since 1998, I have been the Director of Research & Development and have focused my efforts on the development of new technologies to increase the success of restoration projects while reducing costs. I have successfully written Small Business Innovative Research Grants worth $160,000 and have existing Cooperative Research and Development Agreements with the USDA—Agriculture Research Services, COE—Cold Regions Research and Engineering Laboratory, and the DOI—Bureau of Reclamation. We are now in the process of writing a new CRADA with HPGRS to allow for collaboration on the VLSA remote sensing project headed by Dr. Booth.

Our company specializes in the restoration of plant communities and ecosystems on highly disturbed lands. We work throughout the arid, semi-arid, and Mediterranean climates of the western United States. We design, construct, and monitor restoration projects for the US Department of Defense, US Army Corps of Engineers, USDI Bureau of Land Management, USDI National Park Service, USDA Forest Service, and other

445 Quast Lane, Corvallis, Montana 59828 • (406) 961-4991 Fax: (406) 961-4626
3702 Via De La Valle, Suite 202A, Del Mar, California 92014 • (858) 481-5865 Fax: (858) 481-5870
11760 Atwood Road, Suite 5, Auburn, California 95603 • (530) 745-9814 Fax: (530) 745-9817
www.bitterrootrestoration.com e-mail: sales@bitterrootrestoration.com consulting@bitterrootrestoration.com

entities throughout the United States and Canada. We are in the process of expanding our geographic range to include international sites. Currently, we are proposing projects in Eastern Europe and the Middle East.

We have on-staff experts in the fields of restoration ecology, plant physiology, seed biology, horticulture, botany, landscape architecture, Geographic Information Systems, wildlife biology, geology, and phytotoxicology. In addition, we have close relationships with academic experts in the fields of soil science, mycorrhiza, and remote sensing. We annually produce over 2-million seedlings at our nurseries in Corvallis, Montana and Lincoln, California. Our projected revenue for 2003 is $6.2-million. We have sufficient greenhouse capacity to produce 3-million seedlings annually and have developed production protocols for over 300 plant species native to the western United States. Our field project crews install several hundred thousand seedlings annually and are experienced in the installation of site amelioration techniques.

Over the past four years, BRI has focused on the development of GIS and site assessment technologies. I personally headed a project in which we evaluated environmental damage to the 11,000+ acre Anaconda Uplands Superfund Site and incorporated GIS into the planning process. GIS was used to model a baseline vegetation community data and to create spatial models for predicting the distribution of native plant communities on the contaminated site. Furthermore, Dr. Paul Hansen of our staff has developed standardized field assessment techniques and an extensive online GIS database for the Bureau of Land concerning management of riparian areas. Clare Fitzgerald, M.S. in GIS, has developed GIS projects in San Clemente Island, California and northwestern Washington to survey, inventory and map elements of management concern for these respective areas.

Our intention is to further our collaboration with Terry Booth and integrate his VLSA technology with GIS. BRI will assist with the development of the VLSA system and incorporate GIS tools customized for range managers. BRI will seek grant money through USDA Small Business Innovation Research Program to fund our portion of the research. Given our extensive work in the private sector and large client base in the western United States, we can effectively commercialize any products created during this venture.

Thank you for the opportunity to provide this letter.

Sincerely,

Tim W. Meikle
Director of Research & Development

Enclosures:
Catalog

UNITED STATES DEPARTMENT INTERIOR BUREAU OF LAND MANAGEMENT **INTERAGENCY/INTRA-AGENCY AGREEMENT**	PAGE 1 OF 2 PAGES 1. IDENTIFICATION a. BLM IA No:: KAI000005 b. USDA/ARS IA No:: 00-0A-5409112 c. Modification No: d. Task Order No:
Note: By signing this document, the participating agencies accept this agreement and agree to perform in accordance with the terms, conditions, and any attachments hereto.	2. TYPE OF ACTION: (Check one) (X) New Award ( ) Modification ( ) Task Order
3. NAME, ADDRESS, AND TELEPHONE NO. OF INITIATING AGENCY CONTRACTING OFFICER Luis Maestas Bureau of Land Management 5353 Yellowstone Road; P.O. Box 1828 Cheyenne, Wyoming 82003 Phone No. (307) 775-6057	5. NAME, ADDRESS, AND TELEPHONE NO. OFUSDA/ARS AUTHORIZED OFFICER Jim Quaratino, Contract Specialist Donna Navratil, Budget & Fiscal Officer USDA, ARS, Northern Plains Area 1201 Oakridge Dr., Suite 150 Fort Collins, CO 80525-5562
4. NAME, ADDRESS, AND TELEPHONE NO. OF INITIATING AGENCY CONTRACTING OFFICERS REPRESENTATIVE Donald L. Glenn Bureau of Land Management Wyoming State Office, WY950 P.O. Box 1828 Cheyenne, WY 82005 Phone: (307)775-6113 E-mail: Don_Glenn@blm.gov	3. NAME, ADDRESS, AND TELEPHONE NO. OF USDA/ARS PROJECT MANAGER Terry Booth USDA, ARS High Plains Grasslands Res. Station 8408 Hildreth Road Cheyenne, WY 82009 Phone (307)772-2433 E-mail: tbooth@lamar.colostate.edu
6. AUTHORITY: *Economy Act (31 U.S.C. 1535) & 48 CFR 17.503*	7. AGREEMENT PERIOD From: (Date of Signature) To: September 30, 2000
8. ACCOUNTING AND APPROPRIATION DATA ARS: 0085409260 WY930 1020-BR 25 2U 8a. BILLING PROCEDURE TO BE USED: OPAC	9. FUNDING AND FINANCIAL INFORMATION Funding Source: BLM — Amount: $ 112,000 (NTE) $ $ Total Amount of Funding: $112,000 (NTE)
8b. METHOD OF PAYMENT ( ) Advance (X) Reimbursement ( ) Progress	9a. AMOUNT OBLIGATED BY THIS ACTION: (NTE) $112,000.00

10. PROJECT TITLE/BRIEF DESCRIPTION

a. Purpose: This agreement is made and entered into between the U.S. Department of the Interior, Bureau of Land Management, Wyoming State Office (BLM) and U.S. Department of Agriculture, Agricultural Research Service (ARS)for the purpose of conducting research on how to obtain accurate rangeland monitoring information in accordance with the attached Project Outline. The general study area will be the Muddy Creek Watershed, a tributary to the Little Snake River located between Rawlins and Baggs, Wyoming. The ARS will utilize cover measurements from Very Large Scale Aerial (VLSA) photography as a standard for monitoring rangelands.

b. Objectives: The objective of this work is to test the following assumptions:

(1) that VLSA photography can be used to obtain statistically adequate samples for all parts of rangeland watersheds;

(2) that modern software can be used to accurately measure cover and bare ground from VLSA photography in a highly repeatable manner; and

(3) that the aerial methods will cost less than ground-based methods.

UNIVERSITY
OF WYOMING

Wyoming Geographic Information Science Center
P.O. Box 4008 • Laramie, Wyoming 82071-4008
(307) 766-2532 • fax: (307) 766-2744 • http://www.wygisc.uwyo.edu

26 June 2003

Dr. Jack Morgan,
Research Leader,
USDA-ARS, WY.

SUBJECT: Collaboration on the use of very large-scale aerial (VLSA) imagery for monitoring rangelands.

Currently, I working as a Remote Sensing Research Scientist at the Wyoming Geographic Information Science Center (WYGISC). Since 1992, I have actively pursued research in ecology using remote sensing and GIS technology. My work has focused on Wyoming although I have worked on projects in other U.S. states and internationally. My expertise is primarily in vegetation mapping and modeling using satellite data and GIS, but I have also worked on micrometeorological issues (wind turbulence over shrub canopies), ecological transport modeling, predictive vegetation modeling and biodiversity issues. I headed the vegetation mapping project for Wyoming for the USGS Gap Analysis Program. Currently I'm mapping shrub communities in SE Wyoming to evaluate changes in mule deer habitat.

Some relevant publications include:

- Reiners, William A. and Kenneth L. Driese. 2003 (*In Press*). *Propagation of Ecological Influences Across Environmental Space.* Cambridge University Press. Non-Refereed Book.
- Reiners, William A. and Kenneth L. Driese. 2001. The propagation of ecological influences through heterogeneous environmental space. *Bioscience* 51(11):939-950.
- Driese, Kenneth L. and W.A. Reiners. 1998. Aerodynamic roughness parameters for semi-arid natural shrub communities of Wyoming, USA. *Agricultural and Forest Meteorology* 88:1-14.
- Driese, Kenneth L., William A. Reiners, Evelyn Merrill, and Kenneth Gerow. 1997. A digital land cover map of Wyoming: A tool for vegetation analysis. *Journal of Vegetation Science* 8:133-146.
- Stoms, David M., Frank W. Davis, Kenneth L. Driese, Kelly M. Cassidy and Michael Murray. 1998. Gap Analysis of the vegetation of the Intermountain Semi-desert ecoregion. *Great Basin Naturalist* 58(3):199-216.

(over)

I visited the High Plains Grassland Research Station along with Dr. Ramesh Sivanpillai in May 2003 to identify opportunities for research using remotely sensed data. Dr. D. T. Booth gave us an overview of the ongoing development of very-large scale aerial (VLSA) imagery to monitor rangelands. This tool would enable private land managers, scientists and governmental agencies to monitor large areas. We also identified opportunities for incorporating satellite-based remotely sensed data for future applications.

Currently, Dr. Booth and I are engaged in interfacing satellite and VLSA data to address problems in rangeland assessments. While VLSA promises to greatly improve monitoring efforts, the ability to effectively interface VLSA and LANDSAT data may further facilitate resource monitoring. I have appreciated visiting and working at the High Plains Grassland Research Station and I look forward to continuing to work with your unit on these important resource monitoring efforts.

Sincerely

Kenneth L Driese

Kenneth L. Driese
Remote Sensing Scientist
Wyoming Geographic Information Science Center
University of Wyoming
Box 4008
Laramie, WY 82071-4008

USDA

United States Department of Agriculture
Research, Education, and Economics
Agricultural Research

DATE: 9 July 2003

SUBJECT: Collaboration on the use of very large-scale aerial (VLSA) imagery for monitoring rangelands

TO: Dr. Jack Morgan, Research Leader
Rangeland Resources Research Unit, Northern Plains Area

FROM: Dr. E. Raymond Hunt Jr., Research Physical Scientist

As one of the nation's foremost remote sensing scientists involved in applying remote sensing imagery to resource inventory and management, I have been especially interested in the techniques and equipment developed by Dr. D. T. Booth of your unit for the assessment and monitoring of rangelands. These techniques fill a critical role in scaling up from plot measurements to satellite estimates, thus our collaborative work will result in high-impact research.

I worked at NASA's Jet Propulsion Laboratory from 1986 to 1989 as a Member of the Technical Staff, at the School of Forestry, University of Montana from 1989 to 1995 as a Research Assistant Professor and Associate NASA MODIS Team Member, and at the Department of Botany, University of Wyoming from 1995 to 1999 as an Assistant Professor. I joined ARS in Beltsville in September 1999 to devote full time to my research applying the science of remote sensing to natural resources management. I have published the following papers (among many) resulting from this research:

1. **Hunt, E. R., Jr.** and Rock, B. N., Detection of changes in leaf water content using near- and middle-infrared reflectances, Remote Sensing of Environment 30:43-54, 1989.

2. **Hunt, E. R., Jr.**, Relationship between woody biomass and PAR conversion efficiency for estimating net primary production from NDVI, International Journal of Remote Sensing 15:1725-1730, 1994.

ars

Hydrology and Remote Sensing Laboratory
10300 Baltimore Avenue, Room 104, Building 007, BARC-West
Beltsville, MD 20705-2350
Phone: 301/504-5278
Fax: 301/504-8931
email:

3. **Hunt, E. R., Jr.**, Piper, S. C., Nemani, R., Keeling, C. D., Otto, R. D., and Running, S. W., Global net carbon exchange and intra-annual atmospheric CO_2 concentrations predicted by an ecosystem process model and three-dimensional atmospheric transport model, Global Biogeochemical Cycles 10:431-456, 1996.

4. **Hunt, E. R., Jr.**, Fahnestock, J. T., Kelly, R. D., Welker, J. M., Reiners, W. A., and Smith, W. K., Carbon sequestration from remotely sensed NDVI and net ecosystem exchange, p. 161-174, In: Muttiah, R. S. (Ed.), From Laboratory Spectroscopy to Remotely Sensed Spectra of Terrestrial Ecosystems, Kluwer, Dordrecht, The Netherlands, 2002.

5. Parker-Williams, A. and **Hunt, E. R., Jr.**, Estimation of leafy spurge cover from hyperspectral imagery using mixture tuned matched filtering, Remote Sensing of Environment 82:446-456, 2002.

6. **Hunt, E. R., Jr.**, Everitt, J. H., Ritchie, J. C., Moran, M. S., Booth, D. T., Anderson, G. L., Clark, P. E., and. Seyfried, M. S., Applications and research using remote sensing for rangeland management, Photogrammetric Engineering & Remote Sensing 69:675-693, 2003.

This last paper resulted from a synthesis of ARS research using remote sensing for rangelands.

Dr. Booth and I first became acquainted while I was at the University of Wyoming and we participated in the Wyoming Hyperspectral Imagery Pilot Project. I learned of Dr. Booth's recent work while attending professional meetings and collaborating on paper 6, above. Immediately, I recognized the potential utility of his equipment to provide ground truth for satellite imagery by pairing earth coordinate-matched VLSA imagery to Landsat pixels. I suggested this research approach to him and we have now completed a preliminary analysis of VLSA / Landsat-pixel correlation at Muddy Creek, Wyoming. This will be followed with a more-detailed effort for the Cottonwood Creek watershed (June 2003) utilizing Dr. Booth's newly-assembled digital camera system. The new system provides, among other advancements, a more accurate means of tagging images with the appropriate earth coordinates and greater image resolution. The greater image resolution can be expected to give even greater accuracy in the measurement of bare ground and plant cover, and therefore a more dependable standard for comparison with satellite-data derived indexes such as NDVI and SAVI.

I have certainly enjoyed visiting the Rangeland Resources Research Unit in Wyoming and Colorado in February 2003, and look forward to a continuing and productive interaction.

DEPARTMENT OF RANGELAND RESOURCES

OREGON STATE UNIVERSITY
202 Strand Agriculture Hall · Corvallis, Oregon 97331-2218
Telephone 541-737-3341 Fax 541-737-0504

27 June 2003

SUBJECT: Collaboration on the use of very large-scale aerial (VLSA) imagery for monitoring rangelands

TO: Dr. Jack Morgan, Research Leader

FROM: Dr. Douglas Johnson, Professor of Rangeland Ecology

I have been ask to write a letter containing a statement of collaboration with Dr. D.T. Booth of your unit and to document my experience in rangeland management and my familiarity with the problems of rangeland assessment and monitoring.

I have been involved with rangeland management and monitoring since 1972 when I began an M.S. degree in Kansas. I received a Ph.D. in range ecology from Colorado State University in 1982 and have worked for Oregon State University since then. My current research interests center on rangeland monitoring, mapping, and modeling (see attached resume).

One of the most important problems in resource management centers on the measurement of the status of key ecological indicators. These indicators are often plant species that vary with managerial practices and indicate the health of the system. Unfortunately, rangeland vegetation measurement is time consuming, labor-intensive work that is often influenced by stress or the personal biases of the technicians. Often the people measuring vegetation are temporary or summer employees that change from year to year. This introduces additional variation in data and complicates analysis and the derivation of valid inferences. As noted by the National Research Council 1994:

> *All existing national-level rangeland assessments suffer from the lack of current, comprehensive, and statistically representative data obtained in the field. Data collected by the same methods over time and by a sampling design that allows aggregation of the data at the national level are not available for assessing federal and nonfederal rangelands... There is an urgent need to develop the methods and data collection systems at both the local and national levels to assess federal and nonfederal rangelands.*

Dr. Booth is developing ground-imaging/monitoring methods that have the potential to substantially improve the way we manage rangelands. We have collaborated on a computer program VegMeasure. VegMeasure is an automated image analysis software package that is designed to speed data collection of plot data, facilitate quantitative analysis, improve data quality, and reduce the labor of rangeland-type vegetation measurements. This program is the outgrowth of discussions Dr. Booth and I had several years ago at the Annual Meeting of the Society for Range Management. Dr. Booth has found our methods to have great application in his work and he arranged to have Mr. Sam Cox from his staff trained at our laboratory. After Mr. Cox's visit, we programmed a calibration routine that emulates their techniques using the "pin table." This calibration and testing routine is unique and very useful. Currently the software is being used by projects at University of California/Davis, University of Alaska/Fairbanks, and several projects in Oregon and Idaho.

Dr. Booth and his staff have made suggestions that have substantially improved the software for their application, and I look forward to continuing cooperation in developing further improvements that will reduce the labor and cost and improve the accuracy and objectivity of rangeland assessment and monitoring.

Sincerely,

Douglas E. Johnson

Douglas E. Johnson
Professor

Enclosure

United States Department of Agriculture

Research, Education and Economics
Agricultural Research Service

July 7, 2003

SUBJECT: Collaboration on the use of very large-scale aerial (VLSA) imagery for monitoring rangelands

TO: Dr. Jack Morgan, Research Leader

FROM: Dr. Steven Seefeldt, Rangeland Scientist

Dr. Booth's development of techniques and equipment for obtaining very-large scale aerial (VLSA) imagery for monitoring rangelands appears to offer VLSA as a powerful tool in ranch planning, monitoring, and management and is an area of research we are very interested in continuing to pursue with your unit. As you know, our units recently completed the 2003 cooperative monitoring effort for the USSES with the June acquisition of approximately 400 VLSA images from 28,000 acres of rangeland, with attendant ground-data collection. Cover and other data derived from VLSA imagery will be compared for precision, accuracy, and cost with several other monitoring methodologies appropriate to the vegetation in the sagebrush steppe -- including the use of Quickbird satellite imagery (cooperative with Dr. Keith Weber, Idaho State University, Pocatello, ID). The utility of the several data sets will be evaluated for effective facilitation of management planning and detection of ecologically important change in the condition or state of monitored rangelands.

The USSES was established in 1920 and rangeland research of very high quality has been conducted here ever since. Records of fire, grazing, climate and land management have been recorded since the establishment of the station. Currently I am the rangeland scientist at the station and I am responsible for research on rangeland restoration after disturbance and developing vegetation management strategies using sheep to manipulate the vegetation and control exotic weeds. I have conduced research on crop-weed interactions in winter wheat in the Palouse region of WA, on measuring the impacts of weeds on pasture systems in New Zealand, and on measuring plant diversity in the sagebrush steppe. I have enjoyed working with your unit, the professionalism of the staff and the quality of the equipment are first rate. This research will lead to changes in how vegetation is measured and monitored throughout the western rangelands. More

Pacific West Area – U.S. Sheep Experiment Station
HC 62, Box 2010 Dubois, Idaho 83423-9602
Voice: 208.374.5409 Fax: 208.374.5582 E-mail: sss@dcdi.net

Agricultural Research - Investing in Your Future importantly, this research will establish a scientific basis for the methodology used to measure vegetation. Our collaboration will lead to a number of important manuscripts that will change how scientists and land managers measure vegetation, especially in arid ecosystems.

Best regards,

Steven Seefeldt

Gregg Simonds
Rangeland Institute
6315 No. Snowview Dr.
Park City, Utah 84098

July 13, 2003

SUBJECT: Collaboration on the use of very large-scale aerial (VLSA) imagery for monitoring rangelands

TO: Jack Morgan, Research Leader
FROM: Gregg Simonds, Principal

I have been ask to write a letter containing a statement of collaboration documenting my experience in ranch and rangeland management and my familiarity with the problems of rangeland assessment and monitoring

I have been consulting for and running ranches since 1973. Our ranching operations have been recognized in many articles, books and by the federal government. . In 1997, U.S. General Accounting Office (GAO) reported, "that Deseret Land and Livestock was a model for self-sufficiency that excels at protecting land and wildlife".

My success has been base on two important elements: one is having great people to work with and having systems to monitor the aspects of our work. Monitoring is key to our planning, learning and rewards systems. Using GAAP (General Accepted Account Principles) I can show people from around the world our financial fitness and they will trust the numbers. However, it is of great angst to me that we have don't have a similar trusted method(s) to show how well we've done with our natural resources. So I've have made developing statistically valid and economic feasible information about the ecological values of a landscape a personal pursue. It is the underpinning of creating managers that know how to manage landscapes sustainability and for them to have the incentives to do so.

I believe its pursuit should garner the focus of the "Manhattan Project" for the Society of Range Management. It will give our research institutes and colleges relevancy to landscape management. Your research unit's development of VLSA imagery acquisition as a rangeland resource-monitoring tool is addressing that need. The multiple-stake holder project that we are initiating at Barrick Corporation's Squaw Valley Ranch, has at its core the need for permanent records of an accurate baseline assessment and consistent follow-up monitoring. The monitoring methods must dependably allow detection of resource changes occurring with the changes in grazing management as dictated by our new ranch-management plan. Since the ranch contains four streams with populations of the threaten Lahontan Cutthroat Trout, monitoring data must be acceptable to all stakeholders, especially those directly involved in the project. Besides Barrick Corporation and myself, the cooperating entities are: BLM, Trout Unlimited, U.S. Fish and Wildlife Service, and Drs. Doug Ramsey and Neil West of Utah State University. I believe Dr. Booth's VLSA methods will meet this monitoring need and I look forward to working with he and his staff at the ranch, to visiting your facilities in Cheyenne, and to exchanging information about the resource and the monitoring efforts encompassed in the Barrick Squaw Valley Ranch project.

Sincerely,

Gregg Simonds

UNIVERSITY OF WYOMING

Wyoming Geographic Information Science Center
P.O. Box 4008 • Laramie, Wyoming 82071-4008
(307) 766-2532 • fax: (307) 766-2744 • http://www.wygisc.uwyo.edu

26 June 2003

Dr. Jack Morgan,
Research Leader,
USDA-ARS, WY.

SUBJECT: Collaboration on the use of very large-scale aerial (VLSA) imagery for monitoring rangelands.

Currently, I coordinate the WyomingView program (sponsored by the USGS) and have responsibility to develop remote sensing applications that will be useful to people of the state of Wyoming. Towards this goal, I work with government agency personnel to promote opportunities for research and application of satellite-based remote sensing applications. I visited the High Plains Grassland Research Station in May 2003 to promote the WyomingView program.

During this visit, I learned that the USDA/ARS Range Resources Research Unit's development of very-large scale aerial (VLSA) imagery offers private land managers, scientists and governmental agencies a tool for monitoring large rangelands. Using this tool it is possible to monitor large areas with unprecedented accuracy and affordability. Moreover, the methods promise a powerful research tool for advancing basic ecology and also for enhancing the utility of LANDSAT data. Dr. D.T. Booth and I decided to collaborate on this research.

Currently, we are engaged in the application of geo-statistical analysis of VLSA data, and in interfacing satellite and VLSA data to address problems in rangeland assessments. While VLSA promises to greatly improve monitoring efforts, the ability to effectively interface VLSA and LANDSAT data may further facilitate resource monitoring. Also the use of geo-spatial analysis techniques to look at bare-ground distribution and connectivity may prove a more useful indicator of rangeland condition than is indicated by simple measurement of percentage bare ground.

In the way of my background, I have experience in processing satellite data to generate information about forest stands, land cover and impact of natural disasters like drought. As part of my dissertation work I made contributions towards estimating the regional forest cover in East Texas using satellite data. I have experience in interpreting aerial photography and in processing several types of remotely sensed data (LANDSAT, AVHRR, IRS-LISS, SPOT, and MODIS) for mapping and change-assessment studies.

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(For example, I am a co-author on reports such as the following: Srinivasan, R., **R. Sivanpillai**, G. Riley and J. Frieddell. 2000. Analysis of land cover/use changes for 1977-1997 along the Wichita River, Texas using LANDSAT MSS & TM imagery). I also have extensive experience in designing and developing spatial databases (GIS) for natural resource management applications and experience in data capture and differential correction of data obtained from Global Positioning Systems (GPS).

I have appreciated visiting and working at the High Plains Grassland Research Station and I look forward to continuing to work with your unit on these important resource monitoring efforts.

Sincerely,

Ramesh Sivanpillai
Remote Sensing Scientist
Wyoming Geographic Information Science Center
University of Wyoming
Box 4008
Laramie, WY 82071-4008