Project Summary

Project Title: **Interactions of Cattle Grazing and Climate Change on Semi-arid Ecosystem Function**

BRD Principal Contact: **David A. Pyke**

Affiliation: **Forest & Rangeland Ecosystem Science Center**

Address: **3200 SW Jefferson Way**
Corvallis, OR 97330

Telephone/FAX: **Phone 541/750-7334; FAX 541/758-7761**

Email: **pyked@fsl.orst.edu**

Duration of project: **1 February 1999 to 31 September 2003**

Annual funding requested from GC program:	**FY 1999**	**$254,543**
	FY 2000	**$581,142**
	FY 2001	**$692,201**
	FY 2002	**$223,850**
	FY 2003	**$113,716**
Total funding requested from GC program:		**$1,865,452**

Biogeographic Feature/Region(s)	**Thematic Area**
1º Arid, Semi-Arid Systems	**1º Biogeochemical cycling, carbon cycling**
2º Grasslands, Rangelands	**2º Disturbance**
	3º Modeling

Key words: **biological soil crusts; biomass; bulk density; canopy coverage; carbon; cattle grazing; CENTURY; climate change; compaction; desert and arid lands; ecosystem science; foodwebs; grasshoppers; grassland/rangeland; human impacts; infiltration; invasive species; invertebrates; leaf area index; landscape; modeling; monitoring; nutrient cycling; nitrogen; nutrient pools; plants; soil; status and trends; terrestrial.**

Abstract: Rangelands are found on all continents, covering up to 30-50% of the earth's surface**.** Most rangelands in the western states are water-limited ecosystems. Therefore small changes in precipitation amount or season may effect biological components that maintain nutrient and water cycles within and energy flow through these ecosystems. The climate of the Intermountain West is generally semi-arid with most of the precipitation coming during the winter. Global circulation models often predict a shift of the summer monsoonal storm track to the north into the Intermountain West. Resource managers have stressed the need to predict changes to ecosystems that might occur with shifts in global circulation patterns**.** The effects of climate shifts on lands where human-induced impacts, such as livestock grazing, occur may result in interactions that will accelerate or cancel the effects predicted by climate alone. Livestock impacts go beyond just herbivory to include trampling and nutrient redistribution that may affect various ecosystem properties differentially. We will determine: (A) the sensitivity and responses of physical, chemical, and biological components along a series of environmental gradients of soil types, precipitation timing, and evapo-transpiration gradients in semi-arid ecosystems of the Intermountain West; (B) the effect various climate and grazing scenarios will have on the ability for ecosystems to sustain current levels of plant productivity, functional composition and C and N pools for the next 50-500 years as well as to predict the response of invertebrates to changes in C and N with grazing and climate change; and (C) the potential impacts of selected policy decisions regarding livestock grazing in the Intermountain West. We will use results from a precipitation shift experiment to provide details on ecosystem changes in plants, soil foodwebs and nutrient pools. A field study will examine responses of plant (biomass, cover, LAI), biological soil crusts, soil food webs, nutrient pools, and soil physical properties (e.g., bulk density, compaction, infiltration) to grazing (piosphere), soil and climate gradients. Results from field studies will be used as inputs into the CENTURY model. We will use CENTURY to investigate the effect of various climate change impacts, such as increased summer monsoonal moisture, on ecosystem processes with various soils and intensities of grazing. We will examine the potential for using remotely-sensed and GIS data for making regional predictions about grazing impacts on Intermountain West ecosystems by taking information from selected BLM Districts and modeling District-level impacts of grazing and climate on ecosystem properties.

TITLE: **INTERACTIONS OF CATTLE GRAZING AND CLIMATE CHANGE ON SEMI-ARID ECOSYSTEM FUNCTION**

BRD PRINCIPAL CONTACT: David A. Pyke, Rangeland Ecologist, USGS Forest and Rangeland Ecosystem Science Center, 3200 SW Jefferson Way, Corvallis, OR; Phone 541/750-7334; FAX 541/758-7761; Email pyked@fsl.orst.edu

OBJECTIVES/JUSTIFICATION: **Need**--Rangelands are dominated by native or introduced plants that vary in structure from graminoids to forbs to shrubs. These systems include grasslands, shrublands, savannas, deserts, tundra, and wetlands where forest trees would not naturally attain greater that 10% coverage (adapted from 38). Rangelands are a major type of land on all continents (FAO 1982 cited in 35). Thirty-four percent of the U.S. is rangeland, with 57% of that land being owned by the federal government (52). Most rangelands in the western U.S. are water-limited ecosystems. Therefore small changes in precipitation timing may effect the biological components that maintain nutrient and water cycles within and energy flow through these ecosystems. **Resource managers need to predict the consequences to ecosystems that might occur with shifts in global circulation patterns** (83).

Human-induced impacts may add to these potential environmental changes from climatic shifts. Rangelands commonly provide forage for livestock production, but plants and soil biological organisms may have adapted to grazing pressure through a long evolutionary history with herds of grazing animals (e.g., the Great Plains and bison) or may lack adaptations to cope with grazing (e.g., the Intermountain West) (45). Severe grazing (e.g., inappropriate grazing seasons or excessive stocking rates) removes vegetation, reduces litter, and destroys biological soil crusts that protect the soil from wind and water erosion (4, 5, 30, 77, 92). Physical properties of soils may be changed with severe stocking rates or poor timing of livestock grazing (1, 29, 87). Changes in vegetation composition (e.g., increases in woody plants or exotic invasives) and reductions in productivity can result in changes in the forms of carbon and the functional groups of microbial decomposers in the soil (39).

If impacts are severe enough to cause these shifts, thresholds of ecosystem function may be crossed that influence water availability, nutrients and energy in these ecosystems (Global Change research needs from Rocky Mtn./Great Basin, PNW, SW Regional Workshops, Bureau of Land Management (BLM) and the National Park Service). The BLM identified a national level Bureau Information Need (BIN) to the USGS concerning Range Health and the Role of Cryptogamic Soil (BLM 1997-98 National BIN #3). Three components of rangeland health are: the degree of soil stability and watershed function; the integrity of nutrient cycles and energy flow; and the presence of functioning recovery mechanisms. **Research is needed to identify where thresholds occur between functioning and non-functioning systems along interacting gradients of soils, climate and livestock grazing (52).**

Land-management practices are affecting ecosystem function worldwide and these activities may accelerate impacts of climate changes (56). Grazing-related changes to ecosystems become more pronounced as humans shift from nomadic or unrestricted practices of livestock management to practices that focus on human settlement (e.g., privatization and ownership of land, homesteading, etc.). The original introductions of livestock into the western US occurred during Spanish colonization 450 years ago. Land privatization in the West began with the 1862 Homestead Act. Successful homesteads occurred on areas where water was readily available. Arid and semi-arid lands were not arable because of the lack of water; therefore, these lands were never claimed by homesteaders. However, homesteaders used these unclaimed lands for livestock forage. Overuse of these public lands eventually led to the passage of the 1934 Taylor Grazing Act. Rangeland improvements (i.e., fence and wells) were built to spread livestock use across under used lands that while maintaining or reducing actual animal numbers. This trend from unrestricted grazing to restricted-use grazing is now occurring in developing countries in Africa and Asia. As these social changes in developing countries occur, we may anticipate that their lands will experience impacts similar to those seen in the U.S. and will require mechanisms for early detection of approaching thresholds to halt ecosystem degradation before it occurs. **Policy makers need modelers and field biologists to refine models for predicting combined impacts of climate and land management practices on ecosystems, thereby providing better policy tools for determining the sustainability of the land** (56)**.**

<u>Background</u> -- The Intermountain West is a biogeographic region of the western US with four physiographic regions, Columbia/Snake River Plateau, Great Basin, Wyoming Basin and Colorado Plateau. The climate of this region is described as semi-arid; however, average annual precipitation throughout the region may be less than that received in the arid true deserts to the south. The prevailing westerly winds carry moist winter air into the region where it is deposited as snow. Soil moisture recharge occurs after snowmelt. Occasionally, summer monsoonal moisture from the southern Pacific or the Gulf of Mexico enters the eastern portion of the region, but this moisture is annually unpredictable.

Although plant communities throughout the Intermountain West are similar (dominated by shrub steppe or salt desert scrub vegetation) (89), the potential vegetation for a site may differ in species composition or in productivity depending on the geology, soils, and climate (97). Changes to soils or climate, whether natural (climate cycles e.g., El Nino Southern Oscillation) or human-induced, will result in concomitant changes in the organisms found in an ecosystem (23). Within the Intermountain West, some vegetation changes are predictable with certain disturbances (e.g., fire converting lands from shrub- to grass-dominated) (42, 90). Most of these changes are major shifts in functional groups of plants. During the past 10,000 years, shifts in temperatures and precipitation distribution have influenced soil formation and plant composition and distribution (46, 50, 79).

An unprecedented change in climate is predicted to occur in the next 50 to 100 years. Releases of large quantities of CO_2, CH_4, and other pollutants are expected to increase global temperatures (51). Direct impacts of increased levels of CO_2 on agricultural and natural plant communities are being addressed by several U.S. programs under the USGCRP. For example, the Department of Energy has funded the Free-Air-Carbon-Exchange experiments to examine ecosystem properties that will change with rises in CO_2 and the Department of Agriculture is emphasizing the impacts of rising CO_2 on forest and rangeland ecosystems (83). Little work is being done in field experiments to examine ecological impacts of shifts in precipitation timing. However, changes in both air and sea surface temperatures are expected to alter distribution and amounts of precipitation (17). Site water balance is the major driving factor for predicting changes in vegetation (53).

At the scale of a management unit (e.g., watershed, allotment or paddock), precipitation amounts do not always correlate positively with vegetation productivity. Nutrient availability may strongly influence composition and productivity (25). In the northern hemisphere, winter-dominated precipitation favors deep-rooted shrubs throughout the Intermountain West (21, 86). Spring and summer precipitation favors herbaceous vegetation that is more efficient in extracting the water and will favor plants with C4 (warm-season) vs. C3 (cool-season) photosynthesis (86). The northern portions of the Intermountain West have few C4 plants, whereas the southern portions of the region have many representatives of both functional groups (89, 90).

To understand the potential impacts of changes in precipitation seasons on a sagebrush steppe site (Appendix 1), the BLM/NBS/USGS funded a cooperative long-term project with Oregon State University and the USDA-ARS. A "rainout" shelter approach was used to shift the winter precipitation of the northern Great Basin to a spring/summer-dominated regime, and to examine ecosystem properties (76). After three years of manipulating precipitation, changes in vegetation composition are being detected in the annual plant community. In addition, soil respiration appears higher with spring-applied precipitation than with winter-applied precipitation, indicating higher activity of soil microbes and roots (8, 75). Continuation of this study is requested.

Since impacts of climate change on natural ecosystems will be expressed only if combined impacts of climate change and human uses result in additive effects, rather than canceling their individual impacts, we must examine climate change impacts in conjunction with human uses. In the Intermountain West, the major land use is livestock grazing. Heavy livestock grazing eliminates palatable plants for the grazing animal and shifts dominance to less palatable, grazing resistant/tolerant species. Successional theories based on this idea (22) led to the development of the rangeland ecological condition classes of potential natural communities (PNC, late, mid-, and early seral; formerly excellent, good, fair and poor condition) used by several federal agencies since the 1950's (52). Recently, the NRC (52) recommended that rangeland condition be evaluated based on factors affecting the functionality of the ecosystem, the water and nutrient cycles, and energy flow. The basis of the NRC approach is to identify thresholds where these ecosystem processes abruptly change on managed rangelands.

Before we identify where thresholds occur, we must measure ecosystem processes along a disturbance gradient. For livestock grazing, the best gradient is the distance from point sources of water (*sensu* piospheres) (3, 4, 5, 6, 7, 26, 40, 63, 64, 82, 84). Water points are generally placed across the landscape to optimize livestock use of the land (74, 85). Within the last 30 years, managers have been increasing the number of water points to improve degraded rangelands by spreading the same density of animals across larger areas of land (46). Livestock managers recognize this gradient in calculating appropriate stocking rates for various types of livestock (full use <1.6 km, 50% use 1.6 to 3.2 km, no use >3.2 km) (31, 34, 35). Throughout the world, placements of water points have been primarily dictated by an animal-centric view, with only secondary considerations given to the impacts on biogeochemical properties of ecosystems.

For understanding livestock impact on ecosystem properties, piospheres provide greater insight into where thresholds for these various properties may lie (3) than can be gained by examining grazing exclosures alone (43). Piosphere development depicts the early stages of livestock-induced desertification (4, 5, 84) and should provide useful information to model livestock impacts on ecosystem properties. Many questions regarding the hydrologic, nutrient cycling, microbial, macro-faunal, and biodiversity impacts along piospheres require better understanding (3).

Most piosphere studies in the US have focused on single water points and ignored soil classes (27, 36) or examined only a single soil class (82). An exception has been an EPA/USDA-ARS study to identify indicators for monitoring rangeland health (pers. comm. J. Herrick & W. Whitford). Because soil characteristics play a major role in the regulation of species composition and production in semi-arid systems, any study of livestock-induced impacts must attempt to remove the variation associated with soil characteristics such as depth, texture, and soil horizons.

Responses of ecosystem parameters along these livestock-use gradients are generally nonlinear (28). Some parameters respond negatively to the distance from water (decline with distance from water), such as soil bulk density, nitrogen, and exotic species (4, 31), whereas others respond positively to distance from water (increase with distance), such as cover or biomass of palatable plants, nitrogen inputs, and soil microbiotic crusts (5, 12).

Shifts in nutrients along these gradients may alter ecosystem foodwebs. Although livestock impacts to nutrient cycling are suspected to be severe near water points, few studies have attempted to document these changes (65). Patterns of fecal deposition and above-ground plant biomass provide at least circumstantial evidence and a mechanism for nutrient redistribution along a piosphere (4, 40). Changes in the form of carbon from under plants to plant interspaces affects microbial C, basal respiration, microbial:organic C ratio and metabolic quotients of soils (39). Shifts in the N patterns within piospheres may occur with a shift from perennial to annual plants nearer the water point. This shift may provide a positive feedback that favors grasshopper populations. Plants mobilize N from senescent leaves and roots, moving it to growing points as amino acids (41). Annuals, including cheatgrass, may move N to maturing seeds. If this is the case, grasshoppers feeding on senescent cheatgrass (*Bromus tectorum*, an exotic annual) will obtain more N, thus more grasshoppers will survive through early instars, and adults in spring may lay more eggs. The net result for grasshoppers would be larger populations feeding on remaining native grasses later in the summer.

Recent results indicate greater total density and significant differences in composition of grasshoppers in heavily grazed areas dominated by cheatgrass than in native-plant-dominated areas (T.B. Graham, unpubl. data). The greater abundance and larger mass of grasshoppers in exotic grasslands are expected to translate into greater herbivory. Since most plant consumption by grasshoppers occurs during late instar and adult stages, when the dominant annual grasses have senesced, feeding is concentrated on the photosynthetically active native grasses. This herbivory occurs when grasses are most susceptible to grazing (16).

On a landscape basis, the only means of predicting the impacts of climate change along with those of human activities on ecosystem properties is through models. One model for estimating changes in terrestrial ecosystems after climate changes is CENTURY (48, 57, 60). CENTURY offers a means of testing ecosystem concepts by providing a tool for integrating carbon, nitrogen and phosphorus interactions and their driving variables. It was developed in the 1980's for Great Plains grasslands, but has been expanded to function in a wide array of ecosystems.

As human populations increase in a given area, livestock and agricultural uses concentrate around settled areas. In the western U.S., this occurred with policies such as the Homestead Act which privatized western lands. As populations grow in Africa and Asia, such concentrations of land uses are also occurring (19, R.Reid and Belnap, per comm). Consequently, examining the impacts of concentrated use in the US may have relevance to land use issues and policy decisions on other continents. Consequently, we will be submitting proposals similar to this one for work in Kenya and Mongolia. These proposals will be submitted to the International Livestock Research Institute (which has already committed $30K to this effort) and NSF.

Global Hypotheses Relating to USGS-GC Long-term Goals

1. We propose to determine the sensitivity and responses of physical, chemical, and biological components along a series of environmental gradients of soil types, precipitation timing, and evapo-transpiration gradients in semi-arid ecosystems of the Intermountain West. The ecosystem components we will measure include: Physical--soil texture, bulk density, compaction, aggregate stability, and infiltration; Chemical--total and mineralizable N, labile and recalcitrant C, pH, major cations and micronutrients; Biological--plant composition, biomass, foliar cover, leaf area index (LAI), grasshopper and other arthropod composition, abundance and guild structure, biological soil crust cover and composition, soil respiration, microbial composition and biomass.

2. We believe livestock grazing and climate changes will interact to produce changes in soil hydrology, nutrient cycling, and biological composition. With the CENTURY model, we will predict the effect various climate and grazing scenarios will have on the ability for ecosystems to sustain current levels of plant productivity, C and N compartments, and plant functional composition for the next 50-500 years. We believe grasshoppers and other arthropods will respond to changes in C and N, either directly or indirectly via plant responses. Therefore, we anticipate being able to use output from CENTURY to predict impacts on invertebrate composition and abundance with changes in livestock grazing and climate.

3. We believe the output from field experiments along grazing gradients and rainout shelters, plus the modeling output from CENTURY, will provide DOI land mangers, private land owners, and government policy makers with science-based predictions of the impacts of livestock grazing in the Intermountain West. The use of soils as a “common denominator” in this study will allow land managers and policy makers to prioritize areas for conservation, rehabilitation, and management actions in this region.

PROCEDURES/METHODS

Specific Hypotheses Relating to USGS-GC 5-year Goals and Objectives--We will list our proposed specific hypotheses (H) or questions (Q) for the goals and objectives outlined in the Recompetition Announcement. The numbers of the specific hypotheses match the Goal and Objective numbering given in the announcement for Goals 1 and 2. For each hypothesis, we will provide our predicted (P) outcome of the experimental test.

H 1.1 If summer monsoonal storm tracks shift further north and west into the Intermountain West, then sensitivity of biological resources in this region will increase because current plant, animal, and microbial communities are not adapted to summer precipitation.

P 1.1 Greater change in plant species composition will occur in the northern and western portions of the Intermountain West because these lands are dominated by cool-season plants and by microbes adapted to winter precipitation regimes, whereas the southern and eastern portions already receive some summer monsoonal moisture. Thus, in more southern regions, dominance of already-present plant communities will shift to more warm-season species, while in the north, cool-season species will be displaced by warm-season species.

Procedure This hypothesis will be tested with a combination of field experimentation and modeling. Field Approaches: The field components will use two approaches: rainout shelters and gradient sampling throughout the Intermountain West. *Rainout shelters*: We will continue to cooperate with the USDA-ARS and Oregon State University in monitoring the impacts of shifts in precipitation on a sagebrush steppe community in eastern Oregon (Appendix 1). Five, 30x12-m rainout shelters are established and instrumented for above and belowground environmental measurements (75). An overhead sprinkler system allows each plot (treatment within shelter) to be watered separately. Well water is monitored and results are pH=8.1, SAR#2.3, conductivity#0.02Sm^{-2}, NO_3-N=0.89mg l^{-1}, K=6.8mg l^{-1}, and S=3.5mg l^{-1}. An "ambient" plot next to each shelter receives only natural precipitation. Shrub cover is measured by line-intercept with three 8-m transects in each climate plot in each shelter. Shrub density is measured in a 2-m belt that surrounds each transect. Herbaceous (grass, forbs, mosses, and lichens) density is counted and cover (including bare ground and litter) is visually estimated in 8, 0.2-m^2 (50-x 40-cm) microplots placed at 1-m intervals along the shrub transects. Two *in situ* N mineralization tubes were placed in each climate plot in each shelter and filled with soil. Three times during the growing season the soil is removed and extracted with 0.2 NKCl. Mineralization is the difference in the available N from the beginning and the end of the sample period. Total C and N are measured at the beginning and end of the growing season. We will add to this design the collection of soil samples from each climate plot per shelter that will be analyzed for bacterial and fungal biomass, nematode numbers and community structure (37). Sampling will be done annually from the 1998/99 through the 2001/02 growing seasons. Comparisons among treatments will be tested using split-plot ANOVA with appropriate transformations applied to data to meet assumptions of parametric tests.

Gradient samples – Ecosystem properties throughout the Intermountain West will be assessed along several environmental gradients. A geographic information system (GIS) will help us in selecting sample sites. Soil mapping units (described by NRCS by a combination of soil texture, soil depth, morphology, etc.), environmental parameters (i.e., monthly average precipitation, monthly average maximum and minimum temperature, and monthly average evapotranspiration), and grazing intensity (measured using cattle piospheres) will be independent variables. The Intermountain West will be divided in four sections roughly equal to NE, NW, SE, and SW quarters to reflect a gradient of summer precipitation potential (most prominent in the SE currently). Over the 2-year sampling period, we will sample 15 piospheres in each quarter. Within each quarter, we will attempt to find five piospheres on soil texture classes with < 20% moisture equivalents, five on soils between 20 and 30% moisture equivalent, and five on soils > 30% moisture equivalents (roughly sands, loams and clays) (9).

With the help of DOI land management agencies (mostly the BLM), we will develop a data layer describing the location of all livestock water points within each cattle-grazing unit. Each water point will be buffered to a radius of 3,800 m from the point (termed the piosphere). Portions of the piosphere with slopes greater than or equal to 10% will not be included because cattle use is restricted on such sites (34). These areas will be overlaid with mapping units for soils. Overlaps among piospheres will be eliminated from sampling to ensure that a single grazing gradient is measured. Eight radial belts, 50-m wide and centered on concentric circles at distances of 50, 125, 300, 800, 1600, 2400, 3200, and 3800 m from the water point will be drawn. For this hypothesis, we will only use data gathered in the radial belts 3,800 m from the water point, because cattle grazing is not anticipated to occur beyond 3,200 m (34). This will allow us to eliminate the effects of cattle grazing and to consider only the soil/climate gradient for testing this first hypothesis. For other hypotheses, all points along the radial distances from the water will be used. We will provide the detailed procedures under this hypothesis.

Sites within each radial belt that occur on the same soil mapping unit will be selected as potential sites. One radial site within each belt will be randomly selected for physical, chemical and biological measurements. A sample area (50x100 m) will be centered on the radius with the long axis of the sample area running parallel to the tangent of the belt (Fig.1). Each sample area will be subdivided into four, subareas (25x50 m). Within a subarea, a 20-m transect will be randomly placed. Canopy coverage of herbaceous plants will be estimated using a modified Daubenmire technique (20) where 10 microplots (0.2x0.5 m) are placed at 1-m intervals along the transect, and the cover class is recorded for each plant species. Shrub canopy coverage will be measured using a line intercept along each 10-m transect. Species not encountered by the coverage techniques will be listed. Stem and leaf biomass will be visually estimated using a double-sampling technique for all plant functional groups (e.g., native vs. introduced plants in each of the following categories: C_3 and C_4 shrubs, C_3 & C_4 perennial & annual grasses, C_3& C_4 perennial and annual forbs). The double-sampling technique insures a quality control for the visual estimates of biomass (10). Leaf Area Index will be measured at dawn or dusk at two randomly selected points along each transect using a pair of Li-Cor LAI 2000 sensors, one above the canopy taking simultaneous measurements when the sampler is measuring below the canopy (88).

Crust composition will be assessed using 20, 25-cm^2 frames randomly placed in each radial belt. Point hits will be recorded for nitrogen-fixing lichens, other lichens, mosses, liverworts, cyanobacteria, rocks, and plant material.

Nitrogenase activity will be determined using the acetylene-reduction method. Twenty samples from each radial belt plot will be collected at random. Samples will be placed in clear, gas-tight tubes and the entire surface wetted to the desired moisture content. Tubes will be injected with enough acetylene to create a 10% acetylene atmosphere. After injection, samples will be incubated for four hours at the desired temperature in a chamber lighted with Chromo50 (5000 K) and cool white fluorescent bulbs. Subsamples (0.25 ml) of the head space within the tubes will then be analyzed for acetylene and ethylene content on a Carle FID gas chromatograph equipped with 2.4-m, 8% NaCl on alumina column, using helium as the carrier gas (30 ml min^{-1}). Calibrations with ethylene standards will be done at the time of observations (13). Results are reported in nmol C_2H_2 m^{-2} h^{-1}. Values obtained will be converted to kg/ha N using a 3:1 ($N:C_2H_2$) ratio. This is based on previous experiments that simultaneously compared *Collema* and *Nostoc* ethylene production rates to N fixation using ^{15}N (S. Phillips and Belnap, unpub).

Chlorophyll *a* concentrations will be used to estimate biomass and to standardize N fixation rates of cyanobacterial crusts. Samples used for nitrogenase activity will be subsampled and extracted with dimethylsulfoxide (DMSO) in the dark for 45 minutes at 65EC (71). Extractions are then shaken and centrifuged. Chlorophyll fluorescence is measured using a Turner digital fluorometer (Barnstead/Thermolyne, Dubuque, IA, USA) calibrated with purified chlorophyll *a*. In addition, HPLC analyses will be used to determine proportions of nitrogen-fixing cyanobacteria.

Six soil samples, consisting of 30 soil sub-samples each, will be collected from each radial belt plot.

Three samples will be from under the canopy of the dominant perennial plant and three

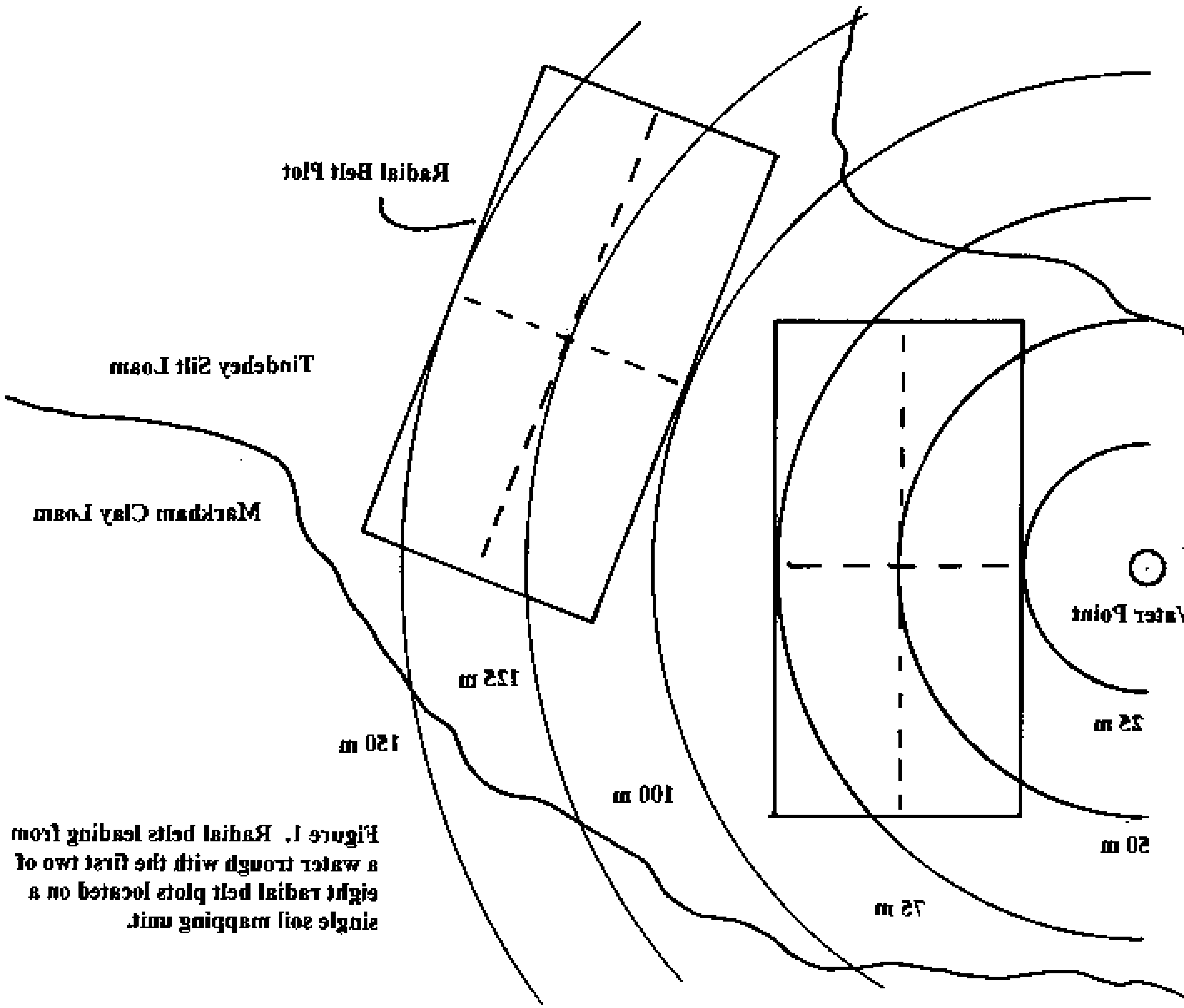


Figure 1. Radial belts leading from a water trough with the first two of eight radial belt plots located on a single soil mapping unit.

samples will be from plant interspaces. These samples will be analyzed for chemical, physical and biological properties. Subsamples will be sent to the BYU Soils Laboratory for analysis of texture, K, Mg, Ca, Na, Mn, Cu, Fe, Zn, CEC, pH, and organic matter (14). Another subsample will be sent to the Soil Foodweb Inc. for analysis of active and total bacteria, fungi and nematode populations (37). As optimum sampling depths for soil food webs vary between climatic regions, preliminary analyses will be done during the first year to determine sampling depths for years two and three.

Soil P and N pools will be analyzed at the University of Denver. For P, both resin and bicarbonate extractions will be done. The pool of exchangeable soil P measured by anion exchange resin extraction is very similar to that assessed with isotopic dilution; in effect, exchange resins offset the equilibrium between dissolved and soluble P. Both exchangeable P and some of the more soluble precipitated P forms that enter the depleted solution are absorbed by the resin (80). Resin extractions will be followed by bicarbonate extraction (55) and the sum of the two extractants used for estimates of "labile" soil P (32). Schoenau et al. (73) suggest that by following the resin extraction with a bicarbonate extraction, labile P adsorbed onto soil colloids is removed and that this is a valid constituent of the exchangeable soil P pool that plants use.

We will analyze for soil nitrogen (N) using several accepted methods. Total soil N will be measured using the Kjeldahl digestion procedure and Lachat QuickChem 8000 automated spectrophotometry (15). In addition, we will estimate available soil N and mineralizable soil N via aerobic incubations. Soil N mineralization is a useful index of the nitrogen-supplying power of the soil. Aerobic incubation involves a 15-day incubation of 20-g samples at 25^{o} C with moisture held constant near field capacity (moist but not anaerobic).

Both ammonium and nitrate will be measured from 100 ml, 2 M KCl solution extracts. Both net mineralization (ammonium + nitrate after incubation minus ammonium + nitrate before incubation) and net nitrification (nitrate after incubation minus nitrate before incubation) will be calculated. Available N is simply ammonium + nitrate before incubation (initial extraction) (70).

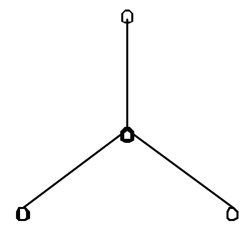
Soil depth will be measured in 10 plant interspaces with a depth probe. Soil surface integrity will be estimated using three techniques. Soil surface shear strength will be measured in 20 plant interspaces with a Torvane shearmeter. Overall surface strength will be estimated using a slake test, where soil samples are immersed in distilled water and time to dispersion of soil particles is recorded (81). Soil cyanobacterial biomass, measured as above, will also be used as an indicator of soil surface stability.

Infiltration will be measured using a standard single-ring infiltrometer (11). Compaction will be assessed using a recording penetrometer and bulk density measurements. Ten penetrometer readings will be taken in plant interspaces from each radial belt plot. Five bulk density cores will be taken at 0-5 cm and 5-10 cm from plant interspaces at each radial belt plot. Cores will be bagged and weighed, returned to the laboratory, oven-dried and then reweighed. Results will be reported as %moisture and g/cm^3 (32).

Vascular plant leaf tissue will be collected from dominant native annual forb, perennial shrub, perennial grass and invasive annual grass, with each sample being a composite of at least 10 individuals from the same locations as the soil samples. Leaf tissue will be analyzed for N, P, K, Mg, Ca, Na, Cu, Mn, Zn, and Fe.

Natural abundance of C and N isotopes will be used to estimate overall contribution of crusts to soil and plant C and N (24). Three samples of surface (0-0.5 cm) and subsurface (6-8 cm) samples, consisting of 30 randomly collected subsamples, will be composted from each radial belt plot. Subsamples of plant tissue (dominant native annual forb, perennial shrub, perennial grass and invasive annual grass) collected for chemical analysis will be used. These samples will be analyzed at the Stable Isotope Facility at the University of Utah.

Invertebrates will be sampled using four pitfall arrays established in each radial site. Each array will consist of four evenly-spaced traps (see figure), with drift fences between the traps. Each trap is 2 m from the closest neighboring trap. Thus, each array covers 12.6 m^2. Traps will be constructed as described in New (54). Each trap is covered by a 625-cm^2 board. This board is elevated above the trap during a sampling session, and pushed down to ground level to close the trap between sampling events.



Invertebrate sampling will take place every six weeks from April through September. Traps will be kept open for a week, during which time traps will be checked occasionally and collected specimens will be removed. Captured invertebrates will be filtered from the ethylene glycol, double-rinsed with water and stored in ethyl alcohol for sorting later. Samples will be sorted into morphospecies and identified to the lowest taxonomic level possible (generally family or genus). Samples may be sent to taxonomic specialists for identification to species, but since this can take considerable time, we will conduct community analyses using these taxonomic designations. Re-analysis will be done if species identifications warrant.

Data will be analyzed using multivariate regressions (GLM ANOVA, MANOVA and ANCOVA as appropriate) to determine which gradients are related to the biogeochemical response variables ($P < 0.1$) (49, 62, 72). Identification of potential sites will occur in the first year, with sampling being conducted during years two and three.

Modeling Approach - Data from the field studies will be used as inputs into the CENTURY model to establish a series of baselines for model initialization. We will use precipitation patterns from areas to the south and east where summer monsoons are presently an important feature of the twelve-month rainfall. By keeping rainfall amount constant, but altering the delivery pattern annually, we will simulate one of the most commonly predicted effects of global change for the Intermountain West. In a second set of simulations, we will increase and decrease temperature variability by ramping small annual increases and decreases in mean monthly maximum temperatures for summer months. Regional synoptic models disagree on the direction of summer temperature changes, but all predict greater variability. By comparing 100 year simulations of temperature and rainfall changes to 100 year simulations based on current patterns, we will estimate effects on above and belowground productivity, erosion and soil fertility. This work will begin in year three and be completed in year five.

H 1.2 & 2.1.3 If grazing is too intensive, then ecosystem productivity is altered because of changes in soil physical, chemical and biological properties. These changes will be more pronounced on soils with a larger range of soil particle sizes.

P 1.2 & 2.1.3 As grazing increases beyond threshold levels, soil physical parameters will degrade (increase for bulk density and compaction; decrease for aggregate stability). Productivity of perennial grasses, C and N, grasshoppers, other arthropods, and soil microorganisms will be reduced, while annual herbs (including exotic invasives) and woody plants will increase with compaction. This will be more pronounced on soils with a large range of particle sizes.

Response variables along a piosphere gradient typically show a sigmoidal (positive or negative) response with distance from the water point (28). The actual shape of the response may differ with changes in soil texture and with climatic factors. It is the shape of the response curve that will provide insight about where thresholds of ecosystem parameters lie and about the sensitivity of parameters to climate or grazing among various soils. We will use the full suite of radial belt sites to test for sensitivity of response variables to a grazing gradient. Thresholds will be apparent when responses are steep and linear as distance from the water increases, whereas continuous gradual shifts will reflect responses that are more resilient to changes.

Multiple regressions and path analysis will be used to determine potential variables that indicate thresholds and to determine their sensitivity to changes. As under H1.1, this portion will begin in year one with site selection and will move into data collection in years two and three with analysis and writeup in years three and four.

H2.2 If plant communities shift to a dominance of annual plants, then grasshoppers will have more severe impacts on native perennial herbaceous plants because of shifts in forage quality and availability, interactions between plant and grasshopper life histories and changes in grasshopper community structure.

P2.2 Increased grazing leads to increased dominance by annual plants and increased bare ground. Total grasshopper density and biomass will increase with increasing annual plant dominance because of greater survival of early instars feeding on annual plants. Grasshopper community structure will change such that the relative abundance of ground-dwelling (terricolous) grasshopper species will increase, and grass-dwelling (graminicolous) species will decrease, with increased bare ground. Consumption of perennial grasses will increase as the relative importance of perennial species decreases because most consumption occurs in late summer/early fall when most of the dominant annual plants are present only as seeds.

Density of grasshoppers will be determined by placing 100 1-m^2 quadrats within each radial plot and moving through the quadrat counting all grasshoppers that hop out. With experience identifying most grasshoppers to species is possible as they hop (if densities are not too high), and counts will be recorded by species. Quadrats will be placed on alternate sides of the transect. Average total grasshopper density will be estimated for each site across quadrats. After density estimates are completed, the surveyor will move through the site and catch and identify the first 100 grasshoppers encountered. If not all species seen during the density surveys are detected, searching will continue until all species have been captured at least once, keeping track of all grasshoppers caught. These can be considered “grasshopper relévés”, a sample of the composition of the grasshopper community, and will be used to estimate the proportion of the community represented by each species. Grasshoppers will be identified to species, and assigned to guilds (18, 58, 59, 61). We will use night cages (2, 78) at each site the first year to sample grasshopper density and species composition This will be used to check the accuracy of the flush-counts and relévés. Grasshoppers will be collected, sorted to "morphospecies," adults identified to species, and all grasshoppers released back into the cage quadrat. Voucher specimens will be collected of all species at all sites.

Biomass will be estimated by capturing 10 individuals of each species at each sample date, drying, weighing and extrapolating to the estimated density. Consumption will be estimated at one piosphere in four major grass types. Cages (1 m^2) in each radial belt plot will be stocked with 3rd instar nymphs of the most abundant species, at estimated maximum densities. Consumption will equal the difference in dried plant biomass in cages with and without grasshoppers, divided by number of grasshopper feeding days (93, 94, 95).

Grasshopper densities will be compared using ANOVA with multiple means comparison tests, or equivalent non-parametric tests. Community structure will be analyzed using canonical ordination (CANOCO). Guild structure will be compared using Chi square tests comparing the proportions of each community comprising graminicolous and terricolous grasshopper species.

Goal 3 We will use CENTURY to scale from site location measurements to regional level analyses for the Intermountain West. The developmental version of CENTURY that is currently being tested allows for scaling across and within vegetation zones. Our approach will be to parameterize CENTURY inputs with data from the local study areas and run the new CENTURY version for the arid grazing lands of the Intermountain West. Through our initial GIS data for the DOI lands, we will have estimates of areas dominated by different soil texture classes. We will use this information to predict regional vegetational changes that might occur with a more prominent summer monsoon in the Intermountain West. This will be done on the three major soil textural classes (sand, silt, clay) and with and without cattle grazing. In this sense CENTURY will be used as an integrative tool at the landscape level.

Goal 4 Data layers developed from field sampling of biogeochemical properties (as related to ecosystem function) and DOI management units (primarily BLM Districts) in the northwestern and the southeastern quadrants of the Intermountain West will be used as input to the CENTURY model to establish baseline conditions. We will use changes along grazing gradients and potential shifts in precipitation seasons as parameters in the CENTURY model to examine the following questions that relate to Objectives 3.1 - 3.4 in the proposal announcement. (Note that numbering of questions does not correspond directly to the BRD GC objective numbers. Alternatively, a single question may relate to multiple objectives):

Q 4.1 If current best management practices for livestock grazing had been applied to Intermountain West lands in beginning in the late 1800s, would the productivity, and C and N pools be the same as they are today?

Q 4.2 If livestock grazing had not been introduced into the Intermountain West, would significant differences in productivity, plant functional groups, and C and N pools differ from what we currently observe?

Q 4.3 If livestock grazing were maintained with the current system and stocking rates for the next 50 years, but precipitation shifted to having more summer monsoons and warmer temperatures, where (e.g., on which soil types) would significant differences in productivity, plant functional groups, and C and N pools differ from what we currently observe?

Q 4.4 If an optimum number of point sources of water for cattle to maximize their use of a management area are developed, what will be the consequences for plant productivity, plant functional groups and N and C pools?

These questions will be addressed through a spatial overlay of grazing gradients and reclassified management-unit data. We will classify management units into grazing-response zones for biological functional groups, C and N pools, and physical site parameters based on the output from field studies and based on predicted responses from climate scenarios run through CENTURY. Grazing response zones will be described using response curves developed from field data, where high grazing response zones will be those asymptotic near the water point, medium zones will occur between distances that describe the inflection points, and low zones will be distances beyond the outer inflection point. We will work with the DOI land managers and policy makers to prepare useful grazing scenarios for the next 50 to 100 years, based on assumptions about grazing systems, stocking levels and grazing season. We will examine the effect of climate change in conjunction with grazing scenarios to predict if higher intensity grazing zones will increase in occurrence, thus indicating a potentially unsustainable grazing regime.

EXPECTED PRODUCTS--The major products generated from this study will fall into four general categories: datasets, metadata, technical reports, and peer-reviewed scientific publications. According to BRD procedures, the project will be described in the BRD Science Information System (SIS). Printed and digital media will be used to distribute the products.

Technical reports will include four annual progress reports, and a final report. Copies of annual reports will be filed at the USGS FRESC Headquarters in Corvallis, OR and submitted to the BRD coordinator. A final report will document the complete findings of the study. Their availability will be described in the SIS and through established pages of the FRESC web site. We also will publish semi-technical reports that summarize the contents of scientific publications in a form useful for policy makers and nontechnical audiences.

We anticipate a series of papers submitted to peer-reviewed journals on the following topics: 1) rainout shelter precipitation shifts versus biological compositional shifts and versus ecophysiological responses; 2) climate/soil gradients versus nutrient pools, microbial, invertebrate, and vegetational composition; 3) grazing gradients versus thresholds for physical, nutrient, and biological components of the ecosystem; 4) model estimations of changes in plant functional groups, nutrient pools related to soil/climate/grazing gradients; and 5) model predictions of the sustainability of grazing in the Intermountain West under various grazing and climate scenarios. As these papers are published, they will be described on the FRESC publication web page The publication of these products also will be described in the SIS record for this project.

Results from field studies will help in refining the development of the CENTURY model for shrub steppe ecosystems of the Intermountain West. We hope to combine GIS modeling with CENTURY to provide a first attempt at predicting the sustainability of current and future grazing regimes in the Intermountain West.

TECHNOLOGY/INFORMATION TRANSFER: Users of this information include both the scientific community and western land managers and policy makers (federal, state and private), including scientists studying exotic plant invasions, nutrient cycles or biological soil crusts; the staff of land management agencies, including range conservationists, recreation specialists, reclamation specialists, etc.; and all people involved in protecting endangered species in western rangelands. Results from this project will be used by research scientists, DOI and private land managers, conservation organizations, and policy makers in determining sustainable land use practices in the Intermountain West. We also anticipate that data gathered on the gradient field plots will be widely sought by other scientists for preparing other grazing/climate/soil gradient models in the future. Results of model outputs will be synthesized with DOI land managers and the results will be presented in a series of workshops along with a consensus report on potential management outcomes. Results will be presented at least 2 national scientific meetings and at the USDA-sponsored biennial scientific meeting for western land managers. Results will also be conveyed to land managers (BIA, BLM, BOR, NPS, USFWS, state and private agencies) during frequent consultations.

DATA MANAGEMENT: Physical and biological attribute data for plots, transects and point locations as well as DOI agency management-unit layers will be maintained in geographic information system (GIS) data sets or as data sets in a compatible relational database management system. Metadata will be developed according to the National Biological Information Infrastructure's (NBII) Profile of the Federal Geographic Data Committee (FGDC) metadata standard. These metadata will be made available to an appropriate NBII Metadata Clearinghouse node within a year of data collection. Completed project data sets will be housed in the Oregon State University, Forest Science Department, Forest Science Data Bank (FSDB). These data sets will be made available to Biological Resources Division partners and customers via the USGS FRESC home page on the World Wide Web within three years of the completion of data collection. They also will be described in the SIS record for the project.

PERSONNEL: David A. Pyke--Principle BRD Contact for Project and Administrative Lead/Rangeland Plant Ecologist -- responsible for administering the project; for interpretation of vegetation results in the field sampling; for relating results to rangeland issues, and grazing management in the Intermountain West. **Jayne Belnap**--Soil Ecologist with a responsibility of overseeing the field sampling of biological soil crusts and microbes, interpretation of results. **Tim Graham**--Invertebrate Ecologist responsible for overseeing invertebrate sampling, analysis, and **interpretation. George Lienkaemper**--GIS Specialist who will be responsible for: working with the land management agencies and gaining GIS coverage when available to help in a site; compiling and serving the metadata for project; working with CENTURY modelers to send them GIS inputs for the model. **Sue Phillips**--Lab manager responsible for analysis and quality control of soil microbial measurements; field logistics; interpretation of vegetation results. **Ruth Jacobs**--Technical Information Specialist with the responsibility of working with the scientists to transfer their results to the appropriate audience and using the most effective means possible.

COOPERATORS/PARTNERS: Robert L. Sanford Jr. Associate Professor, Dept. Biological Sciences, University of Denver, Denver, CO 80208 and Visiting Scientist, Natural Resource Ecology Lab, Colorado State University, Ft. Collins, CO 80523 phone 303/871-3534; FAX 303/871-3471. Responsible for modeling and nutrient cycling analysis and interpretation. DU will contribute maintenance and upkeep of Lachat Autoanalyzer Instrument, $7,473 in tuition matching funds and a 9-month Teaching Assistant position $9,435. **Tony Svejcar**, Rangeland Scientist and Research Leader, USDA-ARS, HC 71, 4.51, Hwy 205, Burns, OR 97720, Phone: 541/573-2064; Fax: 541/573-3042 -- Responsible for overseeing ARS and Oregon State University research on the rainout shelters. A Cooperative Agreement with Oregon State University is in place. USDA-ARS plans to contribute

$22,000 per year for the next five years toward this project. **Dennis Ojima**, Senior Research Scientist, Natural Resource Ecology Lab, Colorado State University, Ft. Collins, CO 80523 phone; 970/491-1976; FAX 970/491-1965. Responsible for CENTURY model analysis and interpretation.

BUDGET:

Item	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003	Total
Salaries						
Term Appointments						
GS-11/01 Ecologist (Plant/Soil)						
0.7FTE in FY99						
1.0 FTE in FY 00, 01 & 02	$23,200	$39,500	$42,000	$43,670		$148,370
GS-11/01 Ecologist (Ecosystem Modeler)						
0.7 FTE in FY 01 & 1.0 in FY 02 & 03			$27,720	$41,696	$44,196	$113,612
(1) Term Appointment Salary Subtotal	$23,200	$39,500	$69,720	$85,366	$44,196	$261,982
(2) Benefits (34% of Term Salary)	$7,888	$13,430	$23,705	$29,024	$15,027	$89,074
Temporary Appointments						
GS-7/01 Temp. Biological Field Tech.						
Soils 0.4, 2.4, 2.8, 0.4 FTE in FY 99, 00, 01, 03;	$10,190	$63,200	$75,800	$11,200		$160,390
GS-5/01 Temp. Biological Field Tech.						
Plants 0.4 FTE in FY 99; 2.8 FTE in FY 00 & 01	$8,300	$59,400	$61,200			$128,900
GS-5/01 Temp. Biological Field Tech.						
Invertebrates 1.4, 2.0,0.7 FTE in FY00, 01, 02	$8,300	$29,050	$41,500	$14,525		$93,375
(3) Temp. Appointment Salary Subtotal	$26,790	$151,650	$178,500	$25,725	$0	$382,665
(4) Benefits (8% of Temp. Salary)	$2,143	$12,132	$14,280	$2,058	$0	$30,613
(5) Total Salary and Benefits (1)+(2)+(3)+(4)	$60,021	$216,712	$286,205	$142,173	$59,223	$764,334
(6) Travel (Airfare, car rentals, per diem, etc.)	$20,350	$20,600	$30,766	$21,855	$22,510	$116,081
(7) Vehicle	$10,200	$18,000	$19,440	$4,423	$4,501	$56,564
(8) Supplies	$45,000	$7,519	$7,745	$2,400	$2,472	$65,136
(9) Equipment						
2 Li-Cor LAI 2000 Analyzers w/ 2 sensors	$15,242					$15,242
2 Soil sampling trailers	$60,000					$60,000
1 Gas chromatograph	$9,000					$9,000
(10) Contracts						
N isotopes	6000	144000	144000			294000
Soil Chem	1800	43200	43200			88200
Plant Chem	2400	57600	57600			117600
Soil Food Webs	2250	54000	55620	5000	5000	121870
(11) Cooperative Agreements						
Denver University	$22,280	$19,511	$40,625	$37,999	$10,010	$130,425
Natural Resources Ecology Laboratory			7000	10000	10000	27000
ANNUAL TOTALS	$254,543	$581,142	$692,201	$223,850	$113,716	$1,865,452

LEGAL AND POLICY-SENSITIVE ASPECTS--All field collections will be conducted on federal lands. Federal managers will be contacted during the first year to request their permission to gain information on the applicability of their land to the study. Should their land meet the criteria, then before sampling is begun we will provide a copy of the study plan and obtain permission to sample on their land. We will report contact names for sample sites in the Science Information System and in annual reports. Current contacts that have encouraged us to consider their lands include: (1) Canyonlands NP Phil Brueck, 2282 S. Resource Blvd. Moab, UT 84532 435-259-3911 x 2102; (2) BLM Moab Area Office, Lynn Jackson, 301 Dogwood Ave. Moab, UT 84532 435-259-6111; (3) BLM Grand Staircase/Escalante National Monument, Dennis Pope, 337 S. Main. Suite 010, Cedar City, UT 84720 435/865-5111; (4) BLM Idaho Districts, Roger Rosentreter, Research Coordinator, Idaho State Office, 1387 S. Vinnell Way, Boise ID 83709; (5)USDA-ARS, Northern Great Basin Experimental Range, Tony Svejcar, Research Leader, HC 71, 4.51 Hwy 205, Burns, OR, 97720 Phone 541/573-2064; FAX 541/573-3042

WORK AND REPORTING SCHEDULE:

Month	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
Oct.		**H1&2** Cont. site selection and data analysis; Prepare annual report	**H1&2**: Data entry & analysis	**H1&2**: Data entry & analysis; **G1&2**: Climate change output	**H1&2**: Prepare technical report; **G1**: Submit 1st ms.
Nov.					
Dec.			**H1&2**: Prepare and **distribute annual report**	**H1,2&G1,2**: Prepare and **distribute annual report**	**H1,2&G1,2**: Submit technical report; Prepare and **distribute annual report**
Jan.		**Distribute annual report**			
Feb.	**H1&2** Begin site selection	**H1&2**: Prepare for field season; Hire and train field crews	**H1&2**: Prepare for field season; Hire and train field crews; **G1&2**: Modeler trained on CENTURY	**H1&2**: Manuscript prep.; **G1&2**: Refine CENTURY with complete field data	**G2**: Complete grazing impacts predictions w/ CENTURY
Mar.					
Apr.	**H1&2** Test & refine field protocols	**H1&2**: Field sampling	**H1&2**: Field sampling; **G1&2**: Refine CENTURY with H1&2 data		**G2**: Prepare & submit 2nd ms
May				**H1&2**: Submit 1st ms., prepare 2nd ms.; **G1**: Final climate predictions w/ & w/o grazing	
June	**H1&2** Make initial cut of potential sites; Analyze field test data				**G1 & G2**: Prepare and submit technical report on modeling output.
July					**H1,2 & G1,2**: Prepare and **submit final report by 1/31/04**; Present workshop for managers & policy makers on results
Aug.		**H1&2**: Data entry & Analysis	**H1&2**: Data entry & Analysis; **G2**: Prepare GIS data from BLM for model input	**H1&2**: Submit 2nd ms.; **G1**: Prepare ms.	
Sept.					

FACILITIES/EQUIPMENT/STUDY AREAS--Study areas will be federally-managed lands in the semi-arid non-forested portions of the Intermountain West. We will conduct field studies on a variety of shrub steppe range sites (vegetation and soil associates) within this region. These will be upland, not riparian, communities. Specific locations and descriptions will be provided in the annual reports of the project. For the rainout shelter (Appendix 1), the shelters and ambient areas are instrumented with a series of replicated soil and air environmental monitoring equipment (e.g., air & soil temperature, humidity, solar radiation, soil moisture, wind) and are logged daily through a multiplexer Campbell Scientific weather stations and dataloggers. FRESC maintains a state of the art networked

GIS facility (2 Sun Ultra workstations with ArcInfo and ArcView licenses, CalComp Digitizing tablet and a HP Inkjet Plotter), and a mobile soil analysis laboratory (trailer needs replacement, gas chromatograph, fluorimeter, HPLC, microscopes, scales, ovens, computers, recording penetrometer, bulk density equipment, sieves and grinders for soil and plant material preparation). The Colorado State University, Natural Resources Ecology Laboratory maintains and updates the CENTURY model. They have many Unix workstations, microcomputers, and software.

REPORTING REQUIREMENTS: Annual progress reports will be submitted for FRESC review and approval by 15 December of each reporting year. Approved annual report will be submitted by the following 15 January to the USGS-BRD G.C. Coordinator. Final report will be submitted to FRESC by 1 November 2003. FRESC will obtain a scientific peer review of the final report by 15 December 2003. The revised and approved report will be forwarded to the USGS-BRD G.C. Coordinator by 31 January 2004.

QUALIFICATIONS OF PROJECT PERSONNEL:

DAVID A. PYKE

Rangeland Ecologist & Assistant Center Director
Forest and Rangeland Ecosystem Science Center
USGS, Biological Resources Division
3200 S.W. Jefferson Way
Corvallis, OR 97331

Office: (541) 750-7334
Home: (541) 752-9031
FAX: (541) 758-7761
EMAIL: PYKED@FSL.ORST.EDU
http://fresc.fsl.orst.edu/

EDUCATION

Washington State University,	January 1976	B.S. (Range Management)
Washington State University,	January 1977	M.S. (Forest & Range Mgmt)
Washington State University,	June 1983	Ph.D. (Botany)

RESEARCH INTERESTS

Rangeland population ecology of semi-arid plant communities of the Intermountain West.

PROFESSIONAL POSITIONS

1996-present	Assistant Center Director, Forest and Rangeland Ecosystem Science Center.
1991-present	Rangeland Ecologist, Forest and Rangeland Ecosystems Science Center.
1987-1991	Assistant Professor, Department of Range Science, Utah State University.
1985-1987	NSF Postdoctoral Fellow, Department of Range Science, Utah State University.
1984-1985	NATO Postdoctoral Fellow, School of Plant Biology, Univ. Coll. of N. Wales
1983-1984	Visiting Asst. Prof., Depts. of Botany and Biology, Washington State Univ.

SELECTED PERTINENT PUBLICATIONS (n=36)

Pyke, D.A**.** and S. Archer. 1991. Plant-plant interactions affecting plant establishment and persistence on revegetated rangeland. J. Range Manage. 44:550-557.

Archer, S. and D. A. Pyke. 1991. Plant-animal interactions affecting plant establishment and persistence on revegetated rangeland. J. Range Manage. 44:558-565.

Pyke, D. A. and S.J. Novak. 1994. Cheatgrass demography -- Establishment attributes, recruitment, ecotypes, and genetic variability. Pages 12-21, *In:* Monsen, S. B. and S. G. Kitchen (compilers) Proc. -- ecology and management of annual rangelands; 1992 May 18-21; Boise ID. USDA For. Serv. Gen. Tech Rep. INT-GTR-313, Intermnt. Res. Stn., Ogden, UT.

Pyke, D. A. 1995. Population diversity with special reference to rangeland plants. Pages 21-32, *In*: West, N.E. (ed.), Biodiversity of Rangelands. Natural Resources and Environmental Issues, Vol. IV, College of Natural Resources, Utah State Univ., Logan, UT.

Huber-Sannwald, E., D. A. Pyke, and M. M. Caldwell. 1996. Morphological plasticity following species-specific recognition and competition in two perennial grasses. Amer. J. Bot 83:919-913.

JAYNE BELNAP

Research Ecologist & Field Station Leader	Office: (435) 259-3911
Forest and Rangeland Ecosystem Science Center	Home: (435) 259-5539
USGS, Biological Resources Division	FAX: (435) 259-8628
2282 S. Resource Blvd.	EMAIL: jayne_belnap@nps.gov
Moab, UT 84532	http://fresc.fsl.orst.edu/

EDUCATION

Univ of California, Santa Cruz	1980	B.S. Biology/Environmental Studies
Stanford University	1983	M.A. Ecology
Brigham Young University	1991	Ph.D. Botany and Range

RESEARCH INTERESTS

Surface disturbance on soil resources in semi-arid and arid lands; soil ecology; biological soil crusts; invasive annual grasses; N cycles.

PROFESSIONAL POSITIONS

9/88-present	Research Biologist, USDI, Moab, Utah
1/84-3/87	Research Associate, Brigham Young University
9/80-1/84	NSF Predoctoral Fellow, Stanford University

SELECTED PERTINENT PUBLICATIONS (n=42)

Evans, R. D. and J. Belnap. In press. Long-term consequences of disturbance on nitrogen cycling in an arid grassland. Ecology.

Belnap, J., R. A. Sanford and L. Lungu. 1997. Biological Soil Crusts: Ecological Roles and Response to Fire in Miombo Woodlands of Zimbabwe. Trans. Zimbabwe Sci. Soc. 70:14-20.

Belnap J. 1996. Soil surface disturbances in cold deserts: effects on nitrogenase activity in cyanobacterial-lichen soil crusts. Biol. Fert. Soils 23:362-367.

Belnap J and Gillette, DA. 1997. Disturbance of Biological Soil Crusts: Impacts on Potential Wind Erodibility of Sandy Desert Soils in SE Utah, USA. Land Degrad. Develop. 8:355-362.

Garcia-Pichel, F. and J. Belnap. 1996. The microenvironments and microscale productivity of cyanobacterial desert crusts. J. Phycol. 32:774-782.

Belnap, J. 1995. Soil surface disturbances: Their role in accelerating desertification. Environ. Monit. Assess. 37:39-57.

Belnap, J. and K. T. Harper. 1995. Influence of cryptobiotic soil crusts on elemental content of tissue in two desert seed plants. Arid Soil Res. Rehabil. 9:107-115.

Belnap, J., K.T. Harper, and S.D. Warren. 1994. Surface disturbance of cryptobiotic soil crusts: nitrogenase activity, chlorophyll content and chlorophyll degradation. Arid Soil Res. Rehabil. 8:1-8.

ROBERT LAURIE SANFORD, JR.

Associate Professor
Department of Biological Sciences
University of Denver
Denver, Colorado 80208 USA

Phone (303) 871-3534
FAX (303) 871-3471
E-mail: rsanford@DU.edu

EDUCATION

Ph.D.	1985	University of California, Berkeley	Wildland Resource Science
M.S.	1980	University of California, Berkeley	Wildland Resource Science
B.S.	1977	University of Michigan	Forest Ecology

ACADEMIC EXPERIENCE

1995-present	Associate Professor, Denver University
1996	Fulbright Scholar Harare, Zimbabwe
1992-1995	Assistant Professor, Denver University
1988-present	Senior Research Scientist, Colorado State, Natural Resource Ecology Lab

Research Interests

Nutrient cycling, modelling

Relevant Publications (N= 34)

Vitousek, P., M. and R. L. Sanford, Jr. 1986. Nutrient cycling in moist tropical forests. **Ann. Rev. Ecol. Syst.** 17:137-168.

Sanford, Jr., R. L., W. J. Parton and C. V. Cole. 1989. Soil phosphorus interrelationships with carbon, nitrogen and sulphur: A modeling approach. Pages 30-41, in H. Tiessen (ed.). **Phosphorus Cycling in Terrestrial and Aquatic Ecosystems**. Univ. of Saskatchewan, Saskatoon, Canada.

Zou, X., D. W. Valentine, R. L. Sanford, Jr., and D. Binkley. 1992. Resin-core and buried-bag estimates of nitrogen mineralization and immobilization in Costa Rican lowland rainforests. **Plant and Soil** 139: 275-283.

Fernandes, D.P., and R.L. Sanford, Jr. 1995 Effects of recent land use practices on soil nutrients and succession under tropical wet forest in Costa Rica. **Cons. Biol.** 9:915-922.

Garcia-Oliva, F., R. L. Sanford, Jr. and E. Kelly. 1998. Distribution of organic C and N within soil aggregates size-fractions in a tropical deciduous forest under slash and burn management. **Soil Sci. Soc. Amer. J.** (in Press).

Parker, E.R. and R. L. Sanford, Jr. 1999. The effects of mobile tree islands on soil phosphorus concentrations and distribution in an alpine ecosystem. **Arct. Antarc. Alp. Res.** 31: (in Press).

TIM B. GRAHAM

Canyonlands Field Station, Ecologist	Office: (435) 259-2109
Forest and Rangeland Ecosystems Science Center	Home: (435) 259-8664
USGS, Biological Resources Division	FAX: (435) 259-2106
82 Dogwood Ave.	email: tim_graham@nbs.gov
Moab, Utah 84532	

EDUCATION

Utah State University	June 1986	Ph.D. (Ecology-Biology)
The Evergreen State College	March 1977	B.A. (Marine Ecology)

RESEARCH INTERESTS

Plant-herbivore interactions, in particular, how invasive plants interact with native invertebrates, Large branchiopod ecology and ephemeral pool community ecology

PROFESSIONAL POSITIONS

1996-present	Ecologist, Canyonlands Field Station
1993-1996	Biologist, National Biological Survey/Service, UC Davis Cooperative Studies Unit.
1987-1993	Biologist, National Park Service, Southeast Utah Group NPS, Curecanti NRA, UC Davis Cooperative Studies Unit.

Professional Affiliations

Ecological Society of America
Southwestern Association of Naturalists
Society for Conservation Biology, Colorado Plateau Chapter
Declining Amphibian Populations Task Force

Selected Publications

Graham, T. B. Plant-herbivore interactions: grasses and grasshoppers in Grand Canyon National Park, Arizona. Dissertation, USU, 1986.

Graham, T. B. 1997. Grasshopper communities in native and non-native grasslands of the Colorado Plateau: differences in density and species composition. Paper presented at Learning from the Land, Scientific Inquiry for Planning and Managing the Grand Staircase-Escalante National Monument. 4-5 Nov. 1997, Cedar City, UT. (Abstract in press, Sept. 1998).

Graham, T. B. 1997. Climate change and ephemeral pool ecosystems: potholes and vernal pools as potential indicator systems. "poster" in Impacts of Climate Change and Land Use in the Southwestern United States. USGS Global Change web page: http://www.usgs.gov/sw/.

DENNIS S. OJIMA

Natural Resources Ecology Laboratory		Office:	(303) 491-1976
Colorado State University		FAX:	(303) 491-1965
Fort Collins, CO 80523		EMAIL:	dennis@nrel.colostate.edu

EDUCATION

Pamona College	1975	B.A.
University of Florida	1978	M.Ag.
Colorado State University	1987	Ph.D.

RESEARCH INTERESTS

Understanding of the complex interactions of climate and human activities in a region to predict the outcome of various land use options set by land resources managers and policy entities.

PROFESSIONAL POSITIONS

1996-present	Sr. Research Scientist	Natural Resources Ecology Lab, CSU
1993-1996	Research Scientist	Natural Resources Ecology Lab, CSU
1992-present	Assistant Professor	Rangeland Ecosystem Science Dept., CSU
1990-1991	Visiting Scientist	Office for Interdisciplinary Earth Studies, UCAR
1988-1990	Programme Officer	International Geosphere-Biosphere Programme

SELECTED PERTINENT PUBLICATIONS

Ojima, DS, Kittel, TGF, Rosswall, T, Walker, BH (1991) Critical issues for understanding global change effects on terrestrial ecosystems. Ecological Applications 1:316-325.

Hobbs, NT, Schimel, DS, Owensby, CE, Ojima, DS (1991) Fire and grazing in the tallgrass prairie: contingent effects on nitrogen budgets. Ecology 72:1374-1382.

Ojima, DS, Parton, WJ, Schimel, DS, Scurlock, JMO, Kittel, TGF (1993) Modeling the effects of climatic and CO_2 changes on grassland storage of soil C. Water Air Soil Poll. 70:643-657.

Ojima, DS, Schimel, DS, Parton, WJ, Owensby, CE (1994) Long- and short-term effects of fire on nitrogen cycling in tallgrass prairie. Biogeochem. 24:67-84.

Schimel, DS, Braswell, Jr. BH, Holland, EA, McKeown, R, Ojima, DS, Painter, TH, Parton, WJ, Townsend, AR (1994) Climatic, edaphic and biotic controls over storage and turnover of carbon in soils. Glob. Biogeochem. Cycles 8:279-293.

Xiao, X, Ojima, DS, Parton, WJ, Chen, Z, Chen, D (1995) Sensitivity of Inner Mongolia grasslands to climate change. J. Biogeogr. 22:643-648.

Ojima, DS, Parton, WJ, Coughenour, MB, Scurlock, JMO, Kirchner,T, Kittel, TGF, Hall DO, Schimel, DS, Garcia Moya, E, Gilmanov, TG, Seastedt, TS, Apinan Kamnalrut, JI, Kinyamario, JI, Long, SP, Menaut, JC, Sala, OE, Scholes, RJ, vanVeen JA (1996) Impact of climate and carbon dioxide changes on grasslands of the world. IN: Breymeyer, AI, Hall, DO, Melillo, JM, Agren, GI (eds), Global change: effects of coniferous forests and grasslands. Wiley & Sons, New York, NY

TONY SVEJCAR

Rangeland Scientist and Research Leader
U.S. Department of Agriculture
HC 71, 4.51, Hwy 205
Burns, Oregon 97720

Phone: 541 573-2064
Fax: 541 573-3042
E-mail: Tony.Svejcar@orst.edu

EDUCATION:

Ph.D.	1982	Oregon State University	Rangeland Sciences
M.S.	1979	Colorado State University	Range Science
B.S.	1977	Colorado State University	Biology

EXPERIENCE:

8/90 - present	Rangeland Scientist and Research Leader, USDA - ARS, Sustainable Management of Rangeland Research Unit, Burns, Oregon
10/86 - 8/90	Range Scientist, USDA - ARS, Landscape Ecology of Rangelands Research Unit, Reno, Nevada
1/83 - -10/86	Research Agronomist, USDA - ARS. Forage and Livestock Research Laboratory, El Reno, Oklahoma.

PROFESSIONAL SOCIETY MEMBERSHIP:

Society for Range Management
Ecological Society for America
American Society of Agronomy
Crop Science Society of America
International Association for Vegetation Science

RESEARCH INTERESTS:

Ecology, ecophysiology and management of Great Basin rangelands. Specific areas include vegetation response to grazing, carbon cycling on rangelands, effects of precipitation timing on rangeland vegetation and soils, western juniper impacts on associated vegetation, and weed ecology.

SELECTED RECENT PUBLICATIONS:

Svejcar, T. and G. R. Riegel. 1998. Spatial pattern of gas exchange for montane meadow species. J. Vegetation Science 9:85-94.

Angell, R. and T. Svejcar. (Accepted). A chamber design for measuring net CO_2 exchange in field plots. J. Range Manage.

Doescher, P., T. J. Svejcar, and R. G. Jaindl. 1997. Gas exchange of *Festuca idahoensis* in response to defoliation and grazing management. J. Range Manage. 50:285-289.

Sheley, R.L., T. Svejcar, and B.D. Maxwell. 1996. A theoretical framework for developing successional weed management strategies on rangeland. Weed Technol. 10:766-773.

SUSAN L. PHILLIPS

Biologist
Canyonlands Field Station, FRESC
USGS Biological Resources Division
2282 SW Resource Blvd.
Moab, UT 84532

Office: 435-259-3911 ext. 2179
FAX: 435-259-8628
EMAIL: sue_phillips@nps.gov

EDUCATION:

University of Utah	1996	M.S. (Biology, Plant Physiological Ecology)
University of Colorado	1986	B.A. (Biology, Plant Ecology emphasis)

PROFESSIONAL POSITIONS:

11/96 - present	Biologist, Canyonlands Field Station, USGS-BRD
5/89 - 10/96	Senior Research Specialist, Department of Biology, University of Utah
5/83 - 2/87	Research Assistant, Institute of Arctic and Alpine Research, University of Colorado

RESEARCH INTERESTS:

Plant physiological ecology and soil ecology of arid and semi-arid ecosystems. Specific areas include plant, community, and ecosystem responses to disturbance and climate change, mechanisms of plant adaptation to contrasting environments, carbon balance, photosynthesis and water relations, use of stable isotopes in ecological research.

SELECTED RECENT PUBLICATIONS (n=16):

Phillips SL, Ehleringer JR, Sandquist DR (in press) Burning coal seams in the Grand Staircase-Escalante National Monument: A natural system for studies of plant responses to elevated CO^2. In Learning from the Land: Science in the Grand Staircase-Escalante National Monument

Ehleringer JR, Phillips SL (in review) Impacts of increased precipitation and neighbors on *Coleogyne ramosissima*, a dominant cold-desert shrub. Journal of Ecology

Lin G, Phillips SL, Ehleringer JR (1996) Monsoonal precipitation responses of shrubs in a cold desert community on the Colorado Plateau. Oecologia 106:8-17

Ehleringer JR, Phillips SL (1996) Ecophysiological factors contributing to the distributions of several *Quercus* species in the Intermountain West. Ann For Sci 53:291-302

Phillips SL, Ehleringer JR (1995) Limited uptake of summer precipitation by bigtooth maple (*Acer grandidentatum* Nutt.) and Gambel's oak (*Quercus gambelii* Nutt.). Trees 9:214-219

Flanagan LB, Phillips SL, Ehleringer JR, Lloyd J, Farquhar GD (1994) Effect of changes in leaf water oxygen isotopic changes on discrimination against $C^{18}O^{16}O$ during photosynthetic gas exchange. Aust J Plant Physiol 21:221-234

Ehleringer JR, Phillips SL, Schuster WSF, Sandquist DR (1991) Differential utilization of summer rains by desert plants. Oecologia 88:430-434

GEORGE LIENKAEMPER

GIS Specialist	Office:	(541) 750-7343
Forest and Rangeland Ecosystem Science Center	FAX:	(541) 758-7761
USGS, Biological Resources Division	EMAIL:	geo@fsl.orst.edu
3200 S.W. Jefferson Way	http://fresc.fsl.orst.edu/	
Corvallis, OR 97331		

EDUCATION

University of Oregon	1969	B.S. (Geology)
University of Oregon	1976	M.S. Interdisciplinary Studies (Geology/Biology/Education)

EXPERIENCE

7/98 – present - GIS Specialist USGS/BRD/Forest and Rangeland Ecosystem Science Center
Duties include development and acquisition of GIS data layers; GIS database design, development and management; consultation with FRESC researchers on GIS project design; GIS analysis; and coordination of metadata development of spatial and non-spatial data sets.

1988 – 1998 GIS Coordinator – Corvallis Forestry Sciences Laboratory – US Forest Service – Ecosystems Process research program. Established the CFSL geographic information system with OSU Forest Science Dept. Coordinated the operation of GIS, including project design consultation; data layer/database development; GIS analysis; ArcInfo software support and troubleshooting; GIS training; and metadata development.

1988 US Forest Service Pacific NW Region, Information Needs Assessment Cadre – part of a team that presented 3-day workshops to resource specialists to prepare each National Forest in the Region for the introduction of GIS technology. The focus was on using resource management objectives to determined the priority of GIS data layer development. Served as the basis for current GIS project design consultations.

SPECIALIZED TRAINING

1988	Introduction to GIS (1 week course)	Portland State Univ., Portland, OR
	ArcInfo (2 week introductory course)	Redlands, CA
1995	ArcView and Avenue (1 week course)	Olympia, WA

PUBLICATIONS

Griffiths R.P., G.A. Bradshaw, B.Marks, and G.W. Lienkaemper. 1996. Spatial distribution of ectomycorrhizal mats in coniferous forests of the Pacific Northwest, USA. Plant and Soil 180:147-158.

RUTH W. JACOBS

Technical Information Specialist — Office: (541) 750-7304
Forest and Rangeland Ecosystem Science Center — FAX: (541) 758-7761
USGS, Biological Resources Division — EMAIL: jacobsr@fsl.orst.edu
3200 S.W. Jefferson Way — http://fresc.fsl.orst.edu/
Corvallis, OR 97331

EDUCATION

Iowa State University, Ames	1976	B.S. (Fisheries & Wildlife Biology)
Oregon State University	1980	M.S. (Wildlife Biology)

EXPERIENCE

1998-present Technical Information Specialist, Forest and Rangeland Ecosystem Science Center
Develop and distribute using a variety of printed and electronic media information about the results of research and technical assistance provided by this USGS science center. Develop and manage databases to allow for efficient archival and retrieval of project information and products.

1990-1997 Research Associate, Department of Forest Resources, Oregon State University
Provide technical assistance, primarily to national parks, on topics related to natural resource management. Assist with the aquatic and wildlife programs of the U.S. Geological Survey Biological Resources Division's Forest and Rangeland Ecosystem Science Center at Oregon State University

1986-1989 Assistant Director, 1990 Acting Director, Office of International Research and Development, Oregon State University
Assistant and Acting Director for the Consortium for International Fisheries and Aquaculture Development, a group of five U.S. universities conducting fisheries and aquaculture research, technical assistance, and training.

PROFESSIONAL INTERESTS

The compilation and dissemination of technical information to enhance wise use of natural resources, with a primary emphasis on national park management.

PUBLICATIONS

Author and co-author of five peer-reviewed journal articles or book chapters, five technical reports, and three management plans.

References

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2. Anderson, NL and JC Wright (1952) Grasshopper investigations on Montana range lands. Mont. Agric. Exper. Stat. Bull. 486.
3. Andrew, MH (1988) Grazing impact in relation to livestock watering points. Trends Ecol. Evol. 12:336-339.
4. Andrew, MH, Lange, RT (1986a) Development of a new piosphere in arid chenopod shrubland grazed by sheep. 1. Changes to the soil surface. Austr. J. Ecol. 11: 395-409.
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13. Belnap, J (1996) Soil surface disturbances in cold deserts: effects on nitrogenase activity in cyanobacterial-lichen soil crusts. Biol. Fertil. Soils 23:362-367.
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Africa. Centre for Applied Social Sciences, University of Zimbabwe, Harare, Zimbabwe.
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43. Laycock, WA (1994) Implications of grazing vs. no grazing on today's rangelands. Pp. 250-280, IN Vavra, M, Laycock, WA, Pieper, RD (eds) Ecological implications of livestock herbivory in the west. Soc. Range Manage., Denver, CO.
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soils by extraction with sodium bicarbonate. U.S. Dept. Agricul. Circ. 939.
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experiments. Chapman & Hall, New York, NY.
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Agron. J. 83:818-825.
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90. West, NE (1983b) Great Basin-Colorado Plateau sagebrush semi-desert. Pp. 331-349, IN: West, NE (ed), Temperate deserts and semi-deserts, Elsevier Sci. Publ., Amsterdam.
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APPENDIX 1 -- PREVIOUS GLOBAL CHANGE PROJECTS

Title: Changes in plant community dynamics caused by elevated CO_2 and altered precipitation.

Period of Work: 1 July 1993 to 30 September 1998

Total Cost: $606,400 BRD; $41,100 USDA-ARS

Summary: An unprecedented change in climate is predicted to occur in the next 50 to 100 years. The release of large quantities of carbon dioxide, methane, and other pollutants are expected to increase global temperatures and change seasonal precipitation patterns through modifications of global circulation. Changes in CO2, temperature, and precipitation will potentially cause major changes in soils, vegetation and biodiversity in the Intermountain sagebrush steppe. Two long-term studies (68) are being conducted to (1) evaluate the response of a Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) community to altered distribution of precipitation (winter-dominated, summer-dominated, versus actual precipitation) by using rainout shelters, and (2) explore the capacity of dominant plants, Wyoming sagebrush (*A. t. wyomingensis*), bottlebrush squirreltail (*Sitanion hystrix* or *Elymus elymoides*), and Thurbers needlegrass (*Stipa thurberiana*) to adjust water use efficiencies (WUE) and carbon-to-nitrogen ratios (C:N) to actual and elevated CO2 levels.

During the summer and fall of 1994, five 30x12 m rainout shelters were constructed (75). An overhead sprinkler system was designed to allow each plot (treatment within shelter) to be watered separately. There was also an "ambient" plot next to each shelter that received only natural precipitation. After two complete growing seasons of altered precipitation we can draw the following conclusions: (1) Annual forbs are very responsive to timing of precipitation; (2) When considered as functional groups, perennial grasses and perennial forbs have not exhibited community-level responses to precipitation timing. Some of the functional responses (such as phenology shifts) may have longer-term consequences on population levels. We have not yet analyzed for individual species shifts within the functional groups; (3) Big sagebrush appears the least responsive (in terms of both community-level and functional parameters) to treatments of the species we've studied. The long-lived woody-plant growth form may have more resilience to environmental change than the other functional groups (8, 76).

Since plants use CO_2 as the substrate for photosynthesis, terrestrial plants may be directly affected by increasing levels of CO_2 in the atmosphere. A replicated controlled-chamber study examined the interactions between edaphic factors and CO_2 to determine how species native to the sagebrush steppe may respond to elevated CO_2. Results suggested that the effect of CO_2 on plant growth and productivity of the sagebrush steppe is dependent on the species, the above- or below-ground portion of the biomass, and on the soil temperature to which the plants are exposed. Water stress did not significantly interact with the CO_2 enhancement effects (44).

Title: Population risks of native perennials and of an exotic annual grass: the role of grazing and climate

Period of Work: 1 July 1993 to 30 September 1998

Total Cost: $349,000

Summary: Although much is known regarding the annual production of forage grasses in this ecosystem, little is know about the population dynamics of the dominant plant species that occur throughout this ecosystem (66, 67), with the exception of *Bromus tectorum* (69). Knowledge of how these species demographically respond to fluctuations in climate under normal management uses, specifically livestock grazing, is needed to predict how this species will react to various global climate scenarios. This study is providing the first attempt to evaluate survival, reproduction, seed survival (seed bank carryover), germination and establishment of a native shrub, Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*), two native perennial bunchgrasses, Thurber's needlegrass (*Stipa thurberiana*) and bottlebrush squirreltail (*Elymus elymoides* formerly *Sitanion hystrix*), and a ubiquitous exotic annual grass, cheatgrass (*Bromus tectorum*). The first phase of the project will determine the baseline demographic information on these species under natural climate variations at three locations in Oregon and Idaho. At two locations, half of the plants are exposed to while the other half are excluded from light autumn or early winter grazing that will provide an ungrazed versus winter-grazed comparison of plant demographic parameters. During the second phase of the study, one-quarter of the grasses will be given a late spring defoliation treatment to simulate late spring grazing treatment to compare with ungrazed and winter-grazed treatments. All sites maintain remote weather stations that collect daily air and soil temperatures and precipitation. These data are compared to the closest local official weather stations. The last phase of the project is to model the impact of changes in weather parameters on the demographic parameters for dominant rangeland plants to determine the impact of climate change on plant populations.

The emergence and survival of seedlings of Stipa thurberiana, Elymus elymoides, and Bromus tectorum were examined at four exclosure sites. At these same sites, soil cores were taken periodically throughout the year to document seed bank behavior. To solve the logistical problems encountered the previous year, a new method for gathering seedling demographic data was developed. This new method involves the planting of individual seed in known locations with specific microsites chosen to gain further insight into spatial patterns of seedling behavior. The seed bank sampling methodology and objectives were also modified in part because of data gathered the previous year. The seed bank portion of this study is now being conducted with researchers working on other aspects of the Vegetation Diversity Project to allow direct comparability of results from similar seed bank investigations. Besides generating baseline data on seed densities and species composition, a major new objective of the study is the evaluation of a set of guidelines for sample stratification that may lead to a new standard for studies in the Great Basin. Nylon mesh bags of seeds of the three grasses were planted in early November of 1995 at two of the exclosure sites to examine the potential longevity of the seeds of these species in the soil environment. Seedbank carryover is < 10% for S. thurberiana and B. tectorum, and was never detected in E. elymoides.