Interactions of cattle grazing and climate on semi-arid ecosystem function

1999 Annual Report

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Abstract

Rangelands cover a large percentage of the earth's surface. Most rangelands are water-limited ecosystems that are sensitive to changes in water availability. The climate of the rangelands of the Intermountain West is generally semi-arid with most of the precipitation coming during the winter. Global circulation models predict a shift of the summer monsoonal storm track to the north into the Intermountain West. The effects of this climate shift in a region where livestock grazing occurs may result in interactions that will influence the effects predicted by climate change alone. Livestock impacts include herbivory, trampling, and nutrient redistribution that affect plant community composition, soil-water relations, soil nutrient cycling, microbial functions, and invertebrate populations. Through the use of a piosphere-based field sampling approach, we will measure sensitivity and responses of physical, chemical, and biological components along grazing gradients. This data will be used as inputs into the CENTURY model to investigate the interaction of various climate change impacts on ecosystem processes. 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. Activities in FY1999 for the piosphere studies focused on preparing protocols, refining methods, and establishing field sites for the first field season in spring/summer 2000. In the precipitation alteration experiment, all shelter treatments tended to have greater ground cover than the Ambient treatment. Herbaceous biomass production and reproductive effort have been reduced under a Spring moisture pattern compared to other treatments. Bareground has been greater in Ambient and Spring treatments than in Winter and Control treatments since May 1996. Annual forb density and cover were consistently lower in Spring treatment compared to the other treatments in all years. The phenology of all the species monitored was affected by the different precipitation treatments. The most dramatic effects occurred with herbaceous species where phenology was delayed or arrested by the Spring treatment (all years) when compared to the other treatments. Sagebrush phenology has been delayed in the Spring treatment through the time of floral shoot development. However, by the ephemeral leaf drop stage there have been few differences in sagebrush phenology among the treatments. Results suggest that summer moisture is an important factor in the reproductive effort of sagebrush and that winter/early spring moisture is important to the reproductive effort of the herbaceous component. In all treatments root activity appears to be correlated to soil moisture conditions particularly in the upper (10-20cm) part of the soil profile. During periods of higher moisture availability root activity increases. Although there has been a lack of any consistent treatment effects with rooting activity it does appear that the Spring treatment may be allocating more resources to below ground structures.

Introduction

Rangelands are found on all continents, covering up to 30-50% of the earth's surface (FAO 1982 cited in Holechek et al. 1989). Most rangelands in the western states are water-limited ecosystems. Therefore small changes in precipitation amount or season may affect biological components that maintain nutrient and water cycles within these ecosystems 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, which favors deep-rooted shrubs (Dobrowolski et al. 1990) and plants with C3 (cool-season) photosynthesis (West 1983a). Occasional summer monsoons bring moisture to the southeastern portion of the region, producing plant communities that include a large proportion of species with C4 (warm-season) photosynthesis (West 1983b). Global circulation models often predict a shift of the summer monsoon storm track to the northwestern portion of the Intermountain West (Bryson 1989), which may induce shifts in plant community composition.

Resource managers have stressed the need to predict changes to ecosystems that might occur with shifts in global circulation patterns (USGCRP 1998). 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 (Ojima et al. 1991). Livestock impacts go beyond just herbivory to include trampling and nutrient redistribution that may affect various ecosystem properties differentially. Identification of functional thresholds at which rangeland ecosystem processes abruptly change has been recommended (NRC 1994). Measurement of ecosystem processes along a disturbance gradient can provide insight into where thresholds lie (Andrew 1988). The best gradient for measuring grazing effects is the distance from point sources of water (*sensu* piospheres) (Andrew 1988). Livestock managers recognize this gradient in calculating stocking rates (full use <1.6 km, 50% use 1.6 to 3.2 km, no use >3.2 km) (Heady and Child 1994).

Objectives

We will determine the sensitivity and responses of physical, chemical, and biological components within piospheres representing a variety of soil types, precipitation timing, and evapo-transpiration gradients in semi-arid ecosystems of the Intermountain West. 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.

Most piosphere studies in the US have focused on single water points and ignored soil classes (Fusco et al. 1995) or examined only a single soil class (Tueller and Platou 1991). Because soil characteristics play a major role in the regulation of species composition and production in semi-arid systems, our study will 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 (Graetz and Ludwig 1978). Some parameters respond negatively to the distance from water, such as soil bulk density, nitrogen, and exotic species (Andrew and Lange 1986a), whereas others respond positively to distance from water, such as cover or biomass of palatable plants, nitrogen inputs, and soil microbiotic crusts (Andrew and Lange 1986b).

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 (Pieper 1994). Patterns of fecal deposition and above-ground plant biomass provide at least circumstantial evidence and a mechanism for nutrient redistribution along a piosphere (Lange 1969). 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 (Kieft 1994). 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 (Larcher 1980). Annuals, including cheatgrass (*Bromus tectorum*, an exotic annual), may move N to maturing seeds. If this is the case, grasshoppers feeding on senescent cheatgrass 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. This herbivory occurs when grasses are most susceptible to grazing (Briske and Richards 1994).

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 (Metherell et al. 1993). CENTURY offers a means of testing ecosystem concepts by providing a tool for integrating carbon, nitrogen and phosphorus interactions and their driving variables. Results from field studies will be used as inputs into the CENTURY model, which will be used to investigate the effect of various climate change impacts, such as increased summer monsoon moisture, on ecosystem processes with various soils and intensities of grazing. We will examine 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 changes.

Predictions from modeling will be used to examine the potential impacts of selected policy decisions regarding livestock grazing in the Intermountain West. We will examine the potential for using remotely-sensed and geospatial 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. The results should provide DOI land managers, private landowners, and government policy makers with science-based predictions of the impacts of livestock grazing. 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.

1999 Progress

The progress in 1999 occurred on two fronts, the piosphere field studies and the precipitation alteration experiment (USDA ARS). The progress for each component is presented in a separate section of this report.

Piosphere Field Studies

The main task for 1999 was planning and preparation for the first field season, which is scheduled to begin in April 2000. This consisted of a series of field trips, pilot studies and protocol development exercises as well as a meeting of the investigators from the two regions involved (northwest Great Basin based in Corvallis OR and Colorado Plateau based in Moab).

Locating and inspecting potential field sites in both regions was done from late September through early November. The process began by consulting with BLM and NRCS staff in each area. We obtained suggestions for sites based on their first-hand experience with the area, and assembled a library of maps and soils information. When possible, preliminary site selection was aided by using layers of pertinent GIS data. Sites on the preliminary list were inspected in the field, resulting in a final list of seven suitable sites in each region. Given our requirements of avoiding overlapping piospheres, staying on relatively homogeneous terrain and soils, and avoiding sites that had been sprayed, burned, or reseeded, suitable sites were less numerous than anyone had expected. Minor deviations from the original site plan may be made at some locations in order to accommodate the variability of terrain, soils, and human manipulations encountered. Sampling is planned in the first year on six sites per region, so we have an extra site in each region as insurance against unforeseen problems.

Field crews were employed throughout fall 1999 to develop, test and verify various soil sampling methods. Test sites were chosen in the vicinity of the Needles and Island in the Sky Districts of Canyonlands National Park, and Arches National Park that had varying degrees of grazing impacts, and that were on different soil types. At each of these sites, the following methods were tested:

1. Soil surface shear strength using a Torvane shearmeter. Field personnel tested the repeatability of measurement within similarly disturbed areas on the same soil type. Data measured with shearmeters made by different manufacturers and of different materials (plastic and stainless steel) were compared. Appropriate sample sizes were determined based on the variability in the data.
2. Soil stability using the slake test. A new slake kit based on specifications provided by J. Herrick (USDA-ARS) was field tested. The kit is currently undergoing further modifications and tests, and will be verified as described for shear strength above.
3. Relative infiltration capacity using unconfined single-ring infiltrometer. Field personnel experimented with and refined techniques for measuring infiltration rates at sites described above. Rings made of PVC were compared with rings made from steel.
4. Soil compaction using an impact penetrometer. The field crew tested three types of impact penetrometers at the field sites described above.

5. Bulk density using corers. The crew tested corers made of various materials at the different sites. This is still ongoing, as results have not been consistent across the different soil types.

Central to our characterization the impacts of grazing on soil nutrient flow will be our ability to quantify cyanobacterial biomass. Accurate biomass measurements will allow for identification of functional group/species composition on a landscape level, and for standardization of nitrogen fixation measurements. The most commonly used methods have involved measuring chlorophyll *a* (chl *a*) content with either a spectrophotometer or a fluorometer. These methods only estimate biomass, and give no information on species composition or function. With the current funding, we have begun to develop an extremely accurate method that can measure chl *a* content, and thus biomass far more precisely. Also, it will provide relative quantities of functional groups, and under some conditions, species composition. Using high-pressure liquid chromatography (HPLC), we have been able to obtain an extremely accurate spectral signature for individual photosynthetic pigments representing species and/or groups of species. Using spectral signatures, one can then detect and subtract out pigments that overlap with chl *a* and thereby get an accurate estimate of chl *a* concentrations. In addition, using the spectrally unique signatures, HPLC analysis will provide data on the relative proportions of individual species present in floristically simple soils. In soils with a more complex flora, HPLC analysis can use the UV-pigment characteristics that separates N-fixers from non-N-fixers to estimate the relative proportions of these two functional groups. In the past six months, we have tested and verified our chl *a* measurements using the HPLC, and are in the process of building a pigment library that will accomplish the remainder of our goals. We expect to have this finished by summer 2000.

Additionally, we have begun to explore better ways to assess soil food webs. We are examining newly developed enzyme assays that will allow extremely accurate counts of active bacterial and fungal biomass. We are investigating the use of RAPD (Random Amplified Polymorphic DNA) methods that provide genetic profiles of soil food web components.

A gas-exchange system is being designed and assembled that will concurrently measure photosynthesis (or respiration) and nitrogen fixation (via the acetylene reduction assay- ARA) in desert crust organisms. The system will include a sample chamber, a computer-controlled gas mixing system, an infrared gas analyzer (IRGA) for quantification of CO2 and a gas chromatograph (GC) with dual columns for automatic sampling of the gas stream for the ARA. So far, all the major instruments are in place, the IRGA, the GC, and the gas mixing system. Code is presently being written for a computer program to control the instruments and record the data for subsequent analysis. Additional methods development is needed for the GC to be fully operational. The entire system should be running for data collection before mid March.

A 10-day meeting in Moab was attended by Dr. David Pyke and David Clausnitzer from Corvallis, and Dr. Jayne Belnap, Sue Phillips, and Dr. Tim Graham from Moab. Because the project involves contrasting ecological regions and multidisciplinary field measurements and lab analyses, the planning sessions dealt with refinement of field and laboratory protocols, discussion of regional conditions, definition of optimum field sampling seasons for each region, and formulation of working strategies for field crews.

The participants made preliminary field trips near Moab to test field protocols. The trial run allowed us to test the feasibility and duration of the planned measurements. It was determined that sampling at each site could be completed by a team of four persons in five days. The double-sampling technique originally planned for biomass estimation was replaced by a procedure involving weighing samples in the field and retaining a subsample of each vegetation type for moisture content determination. It was also decided to observe selected soil morphological features at each of the five locations in each site to verify accuracy of the published soil surveys. Based on the sampling time for each site and consideration of regional climates and plant phenology, we decided to employ two separate field crews.

We tested three methods for estimating grasshopper density. Flush counts were made on 100 1-m^2 plots at each of 10 sites, counting all grasshoppers that hopped out of each plot. Densities were estimated as # m^{-2} based on these counts. Line transects were run at 13 sites, each consisted of 1-3 transects 100 m long. Grasshoppers were counted on only one side of the line, in three belts: 0-30 cm, 30-60 cm, and 60-100 cm from the line. Data were analyzed with DISTANCE to generate density estimates (# m^{-2}). Night cages were used at 6 sites, using 1-m^2 mesh dome tents. Each cage was placed randomly in the study area between 3 and 5 am, when temperatures were lowest and grasshoppers are least active. The number of tents used ranged from 10 to 26 per site. All grasshoppers trapped in cages were counted and an average density calculated.

Comparisons between density estimates from different techniques at individual sites were tested with t-tests or the Kolmogorov-Smirnov two-sample test. Thus there are 10 comparisons between flush counts and line transects, 6 comparisons between night cages and line transects, and 3 comparisons between night cages and flush counts. DISTANCE generates density estimates reported with a coefficient of variation (CV). The CV was used to calculate back to a standard deviation (s) that could be used in t-test calculations.

Line transects consistently generated lower density estimates than either tents or flush counts. Only at Weed Ranch was the line transect estimate larger. One of six comparisons between line transects and tents did not differ (White Rocks 1), and only the Red Sea site estimated from flush counts did not differ from the line transect estimate. Density estimates did not differ between night cages and flush counts at any of the 3 sites. Night cages have been considered to be the most accurate method of estimating grasshopper density, but it is very labor-intensive. Flush counts and line transects take comparable amounts of time, although it is difficult to run line transects alone at even moderate grasshopper densities. It is difficult to know which method actually produces the more accurate estimate, but since flush counts more closely matched night cage estimates, flush counts will be used in the future.

Species composition of grasshopper communities and relative abundance of each species in the community must also be estimated. Flush counts do not necessarily generate this information, nor do line transects. Since night cages allow for handling and thus identification of each grasshopper, species composition can be determined, and numbers of each species captured can be used to calculate relative abundances. At most sites, grasshopper relévés were conducted, where in a random walk through the site, the first 100 grasshoppers encountered were captured and identified, and relative abundance calculated from the proportions of these 100 grasshoppers in each species and the average density estimated for the site. Relévés were conducted at only 3 sites where night cages were employed. At 3 sites with very simple grasshopper communities (2 easily differentiated species), counts during line transects were made separately for each species and could be compared with night cage results.

The distribution of grasshoppers among the species was tested using the Kolmogorov-Smirnov two-sample test for night cage vs. relévé data. At the west desert sites, where there were only two species of grasshopper, Fisher's Exact test was used to compare the percent of the total number of grasshoppers seen during line transects that were *Xanthippus corallipes*, or *Melanoplus confusus* with the percent of grasshoppers captured in night cages of these two species at each site.

There were no significant differences between any of the methods at any site according to these tests. Night cages captured a different suite of species than the relévés did; one or two species were found with one method but not the other. These species were all rare, being represented by only one or two individuals. Relévés appear to describe the community structure of most grasshopper communities except for some rare species, and will continue to be used, although the number of grasshoppers captured, and the area searched will be increased to try to detect all species in the community.

A consumption trial was conducted from 27 July to 1 October 1999 in a *Stipa comata/Bouteloua gracilis* grassland. Five random points were selected on a 100 m transect that was also randomly located at the study area. At each point on the transect, 20 m lines were placed perpendicularly to the transect, and 5 1 m^2 plots delineated at random distances from the main transects. Two plots on each of these 20 m transects were assigned to each of three treatments. Treatments were: 0) Control--no cage, the vegetation was exposed to the ambient grasshopper herbivory (and other herbivores as well); 1) plots were caged and 2 grasshoppers were placed in each cage; and 2) cages were placed on the plots, and all invertebrates were removed.

Total grasshopper density was estimated at the site with 100 1-m^2 plots at 1.3 m^{-2}, thus 2 adult grasshoppers were placed in each cage to approximate the ambient density. Basal cover of each plant species was estimated in each plot before cages were placed over the plots. The cages were occasionally checked and repaired. After two months, cages were removed and all above-ground plant material was clipped, dried and weighed. No grasshoppers were found in the cages at this time; the very cold weather in the latter half of September may have killed the grasshoppers, there were very few grasshoppers seen in the area at this time at all.

This experiment did not work; there were not differences between treatments for any of the plant species in the amount of biomass present. This may have been because two grasshoppers don't eat enough to make a measurable difference, because of inherent differences between treatment plots, or because of differences in growth during the long trial period. Future consumption experiments will use smaller plots, shorter time periods, and higher grasshopper densities.

Precipitation Shift Experiment

All shelter treatments tended to have greater ground cover than the Ambient treatment. Herbaceous biomass production and reproductive effort have been reduced under a Spring moisture pattern compared to other treatments. Bareground has been greater in Ambient and Spring treatments than in Winter and Control treatments since May 1996. Annual forb density and cover were consistently lower in Spring treatment compared to the other treatments in all years. The phenology of all the species monitored was affected by the different precipitation treatments. The most dramatic effects occurred with herbaceous species where phenology was delayed or arrested by the Spring treatment (all years) when compared to the other treatments. Sagebrush phenology has been delayed in the Spring treatment through the time of floral shoot development. However, by the ephemeral leaf drop stage there have been few differences in sagebrush phenology among the treatments. Results suggest that summer moisture is an important factor in the reproductive effort of sagebrush and that winter/early spring moisture is important to the reproductive effort of the herbaceous component. In all treatments root activity appears to be correlated to soil moisture conditions particularly in the upper (10-20cm) part of the soil profile. During periods of higher moisture availability root activity increases. Although there has been a lack of any consistent treatment effects with rooting activity it does appear that the Spring treatment may be allocating more resources to below ground structures.

Plans for Next Year

Planned work for FY2000 includes finalizing detailed planning for field work, obtaining equipment, and hiring and training field crews. The Colorado Plateau crew will begin field work in mid-April; the northern Great Basin crew will spend a training week with the Colorado Plateau crew in early May and then travel north to begin sampling in mid-May. Field work is expected to be finished by August 4 at the latest. New field sites for sampling in FY2001 will be then be located and prepared.

Products

None to report for 1999.

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