

RIO GRANDE BASIN RESEARCH - PROBLEM 1

STUDY PLAN

Study Title: **Restoration of Herbaceous Understory Vegetation in Pinyon-Juniper Woodlands of Central New Mexico**

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Introduction

Desertification of Semiarid Ecosystems

Over the past century, heavy livestock grazing coupled with erratic and extreme climatic patterns on southwestern rangelands has resulted in a substantial reduction in plant production and soil quality. This process, known as desertification, is especially common in arid and semiarid regions with sparse vegetation cover. In the United States alone over 225 million acres may have experienced severe or very severe desertification (Sheridan 1981).

Many of the vegetation associations of the Western United States, including grasslands, were considered fire proclimax ecosystems by Clements (1936) because periodic disturbance by fire maintained a stable plant species composition which prevented the establishment of the "climatic climax". Stability and climatic climax both refer to relatively short-term phenomena based on the human perspective. Relative to ecological time scales, no plant community or vegetation type is permanent. Two of the most extensive fire-dependent ecosystems in the Middle Rio Grande Basin are grassland and pinyon-juniper (P/J) or juniper savanna. Together these ecosystems occupy over 15 million hectares in New Mexico alone (Dick-Peddie 1993). Stable semiarid grassland and savanna ecosystems often were a mosaic of vegetation and bare interspaces. The dynamics of these stable communities may have been similar to systems described by Watt (1947), where the spatial arrangement of vegetation and interspaces changed through time, but the overall amount of space occupied by each component remained the same. Soil erosion from these systems may have been minimal because of the connectivity of the vegetation

and the relative stability of interspace soils which were probably colonized and stabilized by cryptogamic (microphytic) crusts (West 1990).

Warmer climate and increased atmospheric CO₂ are reported to favor a shift from grasslands to woody vegetation (Polley et al. 1993). Suppression of fire in a grassland dominated ecosystem would eliminate the dominant stabilizing force and allow succession to proceed, usually to shrubland at lower elevations, or P/J woodland at higher elevations (Fig. 1). Extensive livestock grazing exacerbates the situation by decreasing herbaceous plant cover and disturbing the structure and stability of surface soils, particularly interspace soils. Loose interspace soils can then be blown under the canopy of vegetation (phase I). It is this process of intrasite soil and nutrient redistribution that results in the formation of islands of fertility (Garcia-Moya and McKell 1970). Often these processes result in the conversion of grassland to shrubland, dominated by nonpalatable species, or to P/J woodland. If this scenario truly results in a redistribution of resources as hypothesized by Schlesinger et al. (1990), and not a net loss of resources, then this process may be reversible.

Continued disturbance would accelerate the expansion and coalescence of bare interspaces. Soil erosion, particularly in areas with significant slope, would increase because connected interspaces would serve as paths of least resistance to water flow (erosion corridors). Soil erosion via these corridors represents nutrient and water export and loss from the system. At this point the system is losing the very constituents it most requires for stabilization and recovery. The ultimate fate of this ecosystem is now under the control of geomorphic processes rather than biological processes. Without intervention, the system can become locked into a negative feedback loop which will stabilize at a state of drastically reduced site productivity (phase II) that may be, for all practical purposes, irreversible (Naveh 1988; El-Tayeb and Skujins 1989; Klein 1989).

Restoration of Semiarid Ecosystems

Restoration of semiarid ecosystems presents many unique challenges. Researchers and land management personnel have observed that following disturbance, semiarid grassland ecosystems will often establish a new stable community dominated by woody perennial vegetation (shrubland or P/J woodland). The new vegetation assemblage often appears to be more stable than the original vegetation. Traditional Clementsian theory predicts that the system would return to grassland if the disturbance was decreased or eliminated, and would remain as a grassland if fire were reintroduced. However, practical application of this approach (removal of disturbance) has yielded little success in many arid land ecosystems around the world (Johnson and Mayeux 1992; Westoby et al. 1989).

One popular explanation of this phenomenon is found in the theory of multiple stable states (vegetation assemblages) in grassland plant communities (Friedel 1991; George et al. 1992; Laycock 1991; Tausch et al. 1993; Westoby et al. 1989). Stable states can be envisioned as being separated by thresholds of disturbance. The magnitude of the threshold is directly proportional to the stability of the vegetation

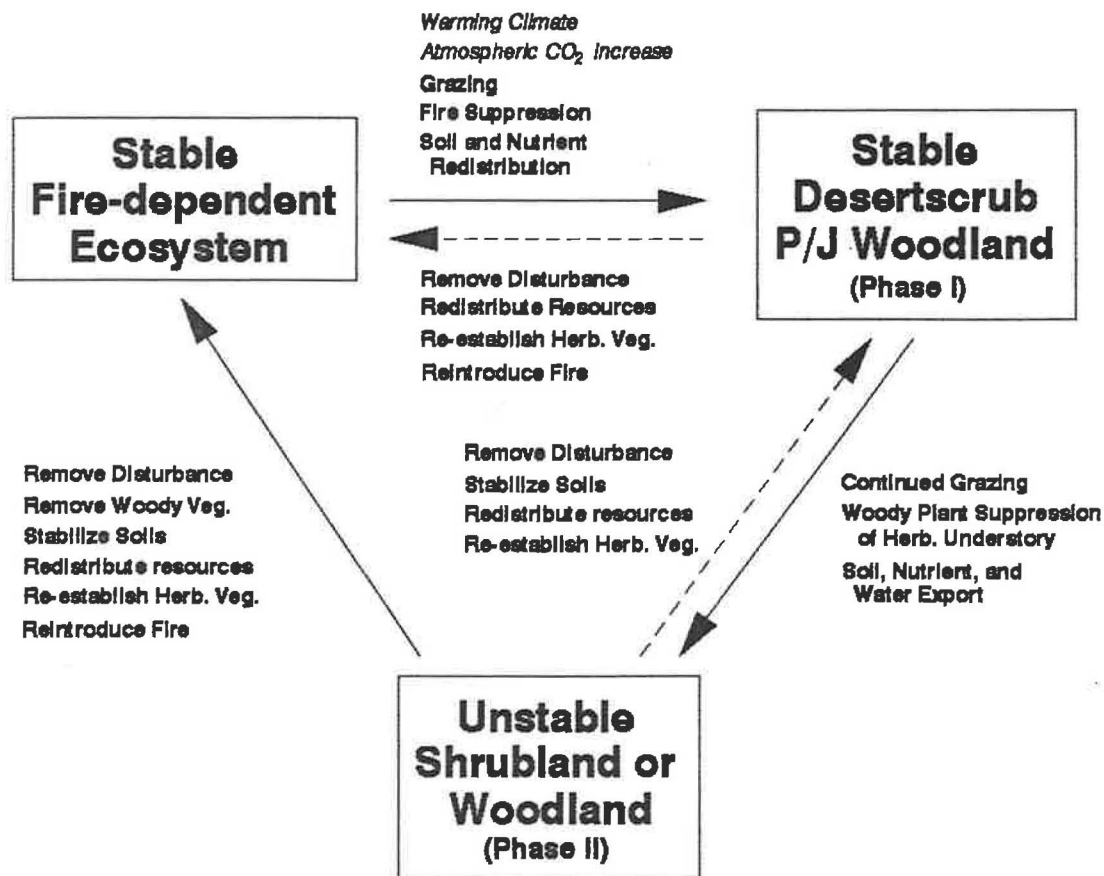


Fig. 1. A conceptual model of desertification/degradation in a semiarid fire-dependent ecosystem. Periodic disturbance by fire is necessary to maintain a grass dominated ground cover. Climate warming and increased atmospheric CO₂ levels may have promoted the growth of woody perennial plants but these processes are beyond the control of the local land manager. However, certain land management practices can initiate desertification. Extensive livestock grazing can reduce standing biomass (fuel loads) and disturb the physical structure of surface soils. Fire suppression and soil nutrient redistribution favor the establishment of shrublands or pinyon/juniper (P/J) woodlands (phase I). Because no net ecosystem loss of nutrients has occurred, restoration of semiarid grassland from desertscrub could conceivably be accomplished by removing the disturbance and redistributing resources to the bare interspaces. Continued disturbance increases aerial coverage of bare interspaces, leading to connected interspaces that serve as erosion corridors for water and nutrient export out of the ecosystem (phase II). The end result is an unstable ecosystem that is rapidly losing the water and nutrients needed to recover former productivity. Restoration of this system, if practical or possible, is dependent upon controlling soil erosion and retaining resources on the site.

assemblage. When a threshold of disturbance is crossed (e.g., overgrazing, fire suppression, soil erosion) and a shrubland or woodland is established, it may become difficult to reestablish a functioning, stable grassland.

The argument for multiple stable states on a site, with semiarid grasslands representing one of those stable states, may be a simple matter of interpretation of past ideas. Clements' own work provides an explanation of the processes observed in the field, and his system can be used to clarify why current management practices do not seem to work in maintaining stable semiarid grasslands. The crux of the problem is the assumption by range management officials that succession in disturbed grassland will eventually reestablish a stable grassland. There are two major arguments against this assumption: 1) Clements (1936) states that many grasslands are disturbance-maintained community types (i.e., grasslands often are maintained by fire). In the absence of periodic fires, many semiarid grasslands become susceptible to invasion by shrubs or P/J, an indication that the "climatic climax" or stable state, for these regions may not be grassland (Humphrey 1953). 2) Many southwestern grasslands are thought to have assembled under more mesic conditions. The climate has since become more arid and atmospheric CO₂ levels have increased, both of which make the environment more favorable for the establishment of shrubs (Johnson and Mayeux 1992; Tausch et al. 1993). These "relict" grasslands have remained stable because of periodic fires but have low thresholds to disturbances such as heavy livestock grazing.

The presence of grasslands at the time of European settlement in the southwest may have led to the erroneous conclusion that grassland was the climax for this area when in fact it was not. Sources of grassland fire include Native Americans, who may have burned grassland to maintain a productive environment. Natural, lightning-caused fires may have been frequent enough to maintain the grassland ecosystem. Current Clementsian management practices are based on the ability of the community to return to "climax" following disturbance. If the true stable state is shrubland or P/J woodland, we cannot expect to reestablish a productive grassland by simply removing the disturbance. In fact, it could take a substantial investment in resources to push the system back to grassland and new management practices would be necessary to keep it there.

Objectives

The purpose of the proposed research is to experimentally test restoration techniques designed to reestablish a stable savanna ecosystem from a degraded woodland ecosystem. To be successful the restoration methods must stop ecosystem degradation (soil erosion) and accelerate the recovery of the herbaceous understory. The specific objectives of this research are to 1) reduce soil erosion and increase water retention using on-site materials, and 2) increase above-ground herbaceous productivity and biomass to the point where fire could be reintroduced as a stabilizing force to maintain a P/J grassland savanna ecosystem.

National Park Service, and National Biological Survey researchers are initiating studies on restoration of P/J herbaceous understory on Bandelier National Monument. One of the major concerns for the Monument is that soil erosion is destroying valuable Anasazi archeological sites. However, at this point, Monument officials are concerned that large scale restoration practices might aggravate erosion problems and increase the risk to archeological resources. The proposed research will be conducted in collaboration with NPS/NBS research and is designed to complement and augment the research on P/J restoration that is being conducted on Bandelier National Monument. Eventually, the methods developed here could be used to stabilize soils, increase herbaceous productivity, and protect threatened historical sites.

Experimental Design

The most effective treatment to reduce soil erosion would be to use tree biomass (slash) as a surface mulch (Chong 1994; USDA Forest Service 1993; Wood and Javed 1991). The timing of the treatment is important to the success of the project. Treatments are planned for Fall 1994 (Bandelier) and Fall 1995 (Santa Fe), after the summer rainy (monsoon) season to prevent excessive soil erosion. The surface mulch would increase surface roughness (resistance to overland flow), thereby retaining water on the site and reducing soil erosion. Surface organic matter should also reduce surface soil temperatures, reduce evaporative soil water loss, and create favorable microsites for plant seed germination and seedling establishment. This treatment would also initiate the process of nutrient redistribution to interspaces and result in a less heterogeneous environment.

Bandelier National Monument

Researchers for the National Park Service and the National Biological Survey are initiating a project within Bandelier National Monument which is designed to test the effects of slash mulch, imprinting (a procedure that creates microsites for seeding) and seeding with native grasses, and fertilization on restoration of P/J herbaceous understory. The P/J woodland sites on Bandelier are characteristic of many of the mesa top woodlands on the Pajarito Plateau, therefore, the results of this study should be applicable to a larger area than just the Monument. Each of two to three study sites will contain three slash-treated areas (Fig. 2). Each slash-treated area will contain a set of 15 X 15 m plots with 1) control (outside slash treatment), 2) slash only, 3) slash and imprinting, 4) slash, imprinting, and seeding, 5) slash and fertilization, and 6) slash, imprinting, seeding and fertilization treatments. All trees within a slash-treated area will be cut and the slash dispersed evenly throughout the area. All plots within a slash-treated area will be at least eight meters from the edge to minimize edge effects from nearby trees. Park Service personnel will implement the treatments within the Monument in the summer/fall of 1994, and will monitor the plots to evaluate vegetation and soil erosion response. Researchers at the Forest and

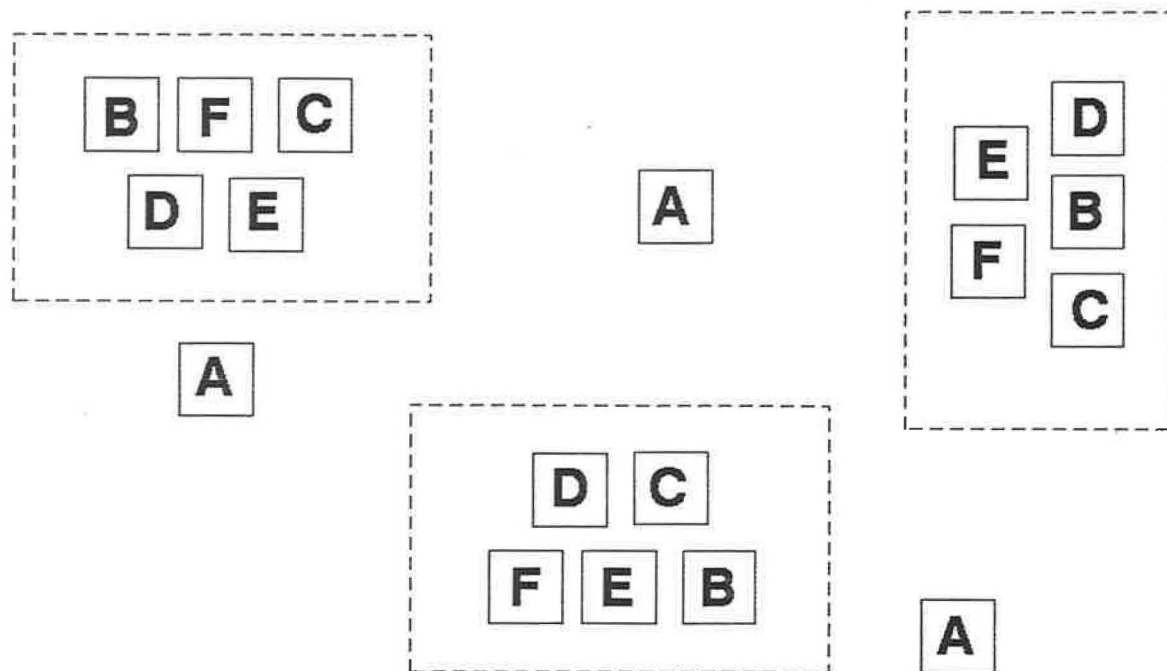


Fig. 2. Experimental design of Bandelier restoration project. Individual study plots (labelled A-F) are 15 by 15 meters. Plots labelled A are no-slash controls. The areas to be slash-treated are shown as dashed rectangles with plots B-F within them. Individual slash-treated areas will be approximately 0.2 - 0.3 hectare. The study plots within the slash-treated areas will receive individual treatments of slash only; slash and imprinting; slash, imprinting and seeding; slash and fertilization; and slash, imprinting, seeding, and fertilization. This design will be used in two to three sites within Bandelier NM, and a modified version, to be used on the Santa Fe Forest, is described in Fig. 3.

Range Exp. St. will characterize pre- and post-treatment (seeded) soil seed banks, and pre- and post-treatment plant nutrient and soil water response.

Santa Fe National Forest

A study site has been established near Guaje canyon on the Santa Fe National Forest, Espanola Ranger District. Forest Service crews (Santa Fe N.F.) will cut a predetermined proportion of the trees, leaving scattered older trees, and spread the material evenly over the surface of the ground. The Fall 1995 treatment will allow researchers time to conduct extensive pre-treatment sampling and establish baseline data for all variables. Figure 3 is a diagram of the experimental design to be used within both the slash-treated and control areas. The control and slash-treated areas will be large enough (10 ha, minimum) for the results to be applicable to large areas and avoid edge effects and other scale problems associated with small plots. Replication of treatments will not be possible, due to monetary constraints. Therefore, interpretation of the results will be confined to the study area and should not be extrapolated to surrounding P/J woodlands. Each treatment area will be stratified into five blocks and each block will contain randomly assigned vegetation, soil sampling, and soil erosion/TDR soil water transects. This design will increase dispersion of sampling transects throughout the study site.

A replicate of the 18 plots used at each site in Bandelier will be established within the Santa Fe Forest study site in the summer/fall of 1994. The 15 X 15 m plots will be placed near the border of the slash-treated area (Fig. 3). Results from these plot studies will be compared to results from the Santa Fe transect analyses as well as results from the plot studies on Bandelier.

Soil cover within P/J woodland can be roughly divided into three categories, bare interspace, herbaceous vegetation and tree canopy. Previous research on Bandelier National Monument has indicated that the treatment response of these cover types can be very different (Chong 1994). Although the sampling design described for this study will incorporate this heterogeneity into the final analysis, it may be possible to modify the analysis to test for treatment effects within cover types, (i.e., portions of vegetation transects and erosion bridge measurements could be grouped into cover types and analyzed separately).

Specific questions to be addressed by this design are: 1) do study areas differ significantly before the application of the treatments? 2) do the treatments (control and slash-treated) have the same effect on the response variables?, 3) do the treatments have the same effect on soil properties at different depths?, 4) do the treatments have the same effect on the response variables between sampling periods? The initial analysis of the soil data will be a repeated measures multifactor analysis of variance with treatment, depth, and time as major factors. The only interactions of interest will be those which include the treatment variables. The final analysis will be a one-way analysis of variance with variables determined by the initial analysis. The statistical analysis of vegetation, soil water, and erosion bridge data, will follow the same procedure with the same or fewer major factors.

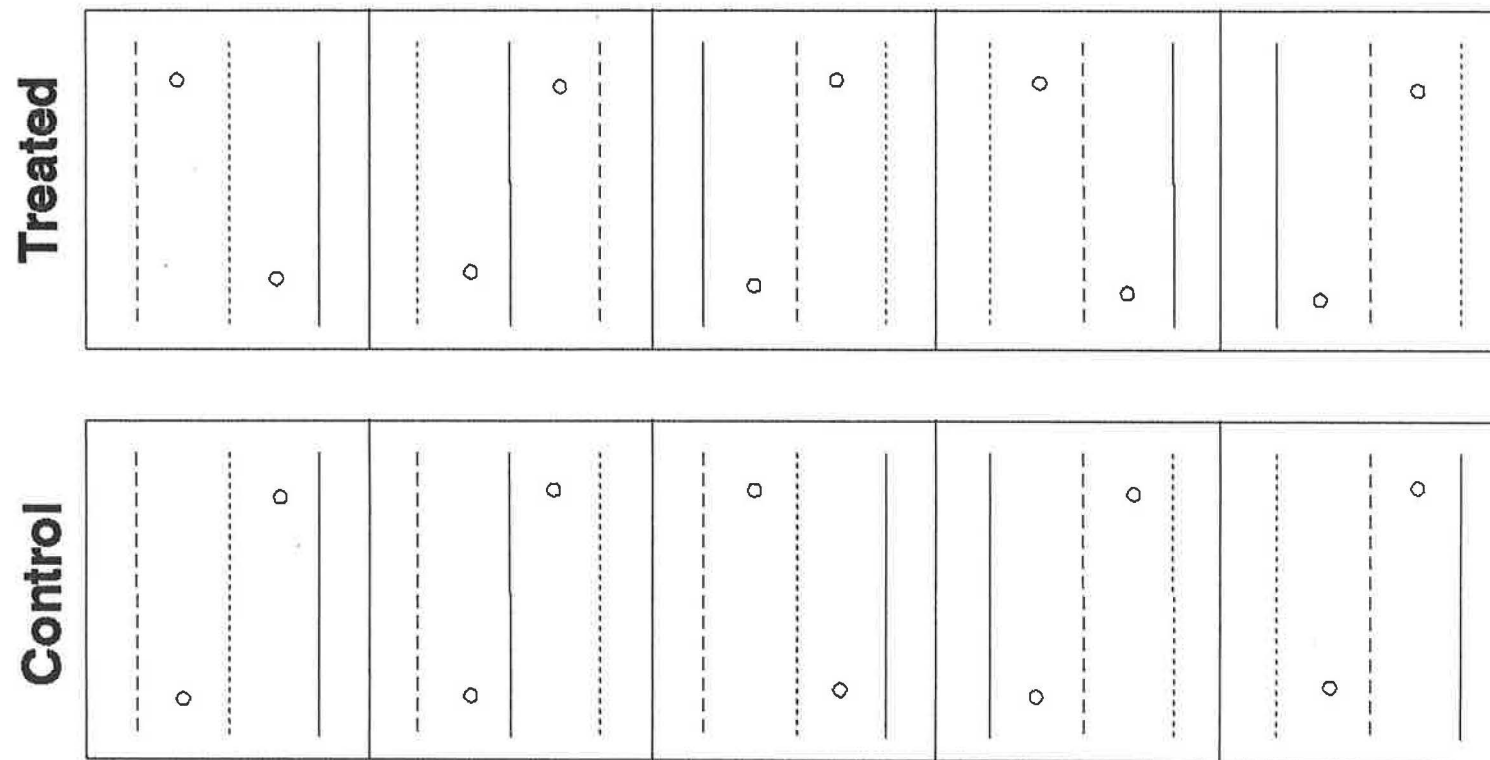


Fig. 3. Stylized representation of the experimental design of the Guaje restoration project. Each treatment area (control and slash-treated) will be roughly divided into five blocks. Within each block a set of three 100 meter transects will be established and each will be randomly dedicated to vegetation analyses (---), soil sampling (...), or erosion bridge (- - -) monitoring. Two Troxler soil water access tubes (○) will be installed in each block. A replicate of the Bandelier study will be established at this site. Three sets of 15 by 15 meter plots will be established on the border of the slash-treated area. The treatments are identical to those described in Fig. 2.

Methods

Surface (0-15 cm) soil water content will be quantified using time domain reflectometry (TDR) instrumentation. Water content of lower soil depths (10-100 cm, in 10 cm increments) will be quantified using a Troxler 200-AP non-nuclear soil moisture probe. The TDR soil moisture probes and erosion bridges will be placed at random locations along five permanent 100 m transects. Erosion bridges (Shakesby 1993) will also be used to monitor soil loss/aggradation.

Soil samples will be collected along five separate permanent 100 m transects. Composite soil samples will be sampled from the surface 0-10 and 10-20 cm and composed of five random subsamples. Five composite samples will be collected from each transect. Soil samples will be analyzed for total organic carbon (Walkley-Black method of wet oxidation), total nitrogen (kjeldahl digestion technique), ammonium and nitrate (KCl extractable), total phosphorus (sodium hydroxide fusion), available phosphorus (sodium bicarbonate extractable), calcium carbonate equivalent (acid neutralization), pH and electrical conductivity by saturated paste, and particle size distribution by hydrometer.

Each site will be monitored for changes in soil surface cover (vegetation, litter, bare soil), plant species abundance and diversity, seedling establishment, and above- and below-ground phytomass. Plant abundance (cover, density, and frequency) and plant species diversity data will be generated using Community Structure Analysis (CSA) (Pase 1981) of five permanent 100 m transects. Quadrats (20 X 50 cm) will be used in conjunction with CSA transects to estimate seedling establishment and growth. Above-ground phytomass estimates will be based on a double sampling technique using clipped plots. Above-ground phytomass samples will also be analyzed for total C and N content.

Root biomass will be estimated from soil cores. Ten random cores (5 X 20 cm) will be collected from each 100 m soil sampling transect. Root biomass cores will be collected approximately 0.5 m off the transect to prevent overlap with soil samples. The root cores will be sieved through a #10 (2 mm) screen in the field to remove the soil. Root samples will then be air dried, ground, and ashed in a muffle furnace to correct for mineral content.

Estimates of seed bank viability will be made by incubating surface soil samples in the greenhouse. Soil samples from the surface 2 cm will be collected from each of the three surface cover categories, bare soil, herbaceous cover, and tree cover. Samples from the Bandelier plots will be collected in early spring 1995, and samples from the Guaje site will be collected in early spring 1996. Soil samples will be spread over potting mix in germination flats and incubated in the greenhouse. Soil samples will be sprayed with a gibberellic acid solution to assist seed germination. Seedlings will be counted and identified on a weekly basis for at least two months.

Literature Cited

- Chong, G.W. 1994. Recommendations to improve revegetation success in a pinon-juniper woodland in New Mexico: a hierarchical approach. M.S. Thesis. University of New Mexico. Albuquerque, NM.
- Clements, F.E. 1936. Nature and structure of the climax. *Journal of Ecology* 24:252-284.
- Dick-Peddie, W.A. 1993. *New Mexico vegetation: past, present and future*. Univ. of New Mexico Press, Albuquerque, NM.
- El-Tayeb, O.M. and J. Skujins. 1989. Introduction: potential of biological processes in desertification control. *Arid Soil Research and Rehabilitation* 3:91-98.
- Friedel, M.H. 1991. Range condition assessment and the concept of thresholds: a viewpoint. *Journal of Range Management* 44(5):422-426.
- Garcia-Moya, E., and C.M. McKell. 1970. Contribution of shrubs to the nitrogen economy of a desert-wash plant community. *Ecology* 51(1):81-88.
- George, M.R., J.R. Brown and W.J. Clawson. 1992. Application of nonequilibrium ecology to management of Mediterranean grasslands. *Journal of Range Management* 45(5):436-440.
- Humphrey, R.R. 1953. The desert grassland, past and present. *Journal of Range Management*. 6:159-164.
- Johnson, H.B. and H.S. Mayeux. 1992. Viewpoint: a view on species additions and deletions and the balance of nature. *Journal of Range Management* 45:322-333.
- Klein, D.A. 1989. Cellulose functions in arid soil development. *Arid Soil Research and Rehabilitation* 3:185-198.
- Laycock, W.A. 1991. Stable states and thresholds of range condition on North American rangelands: a viewpoint. *Journal of Range Management* 44(5):427-433.
- Naveh, Z. 1988. Multifactorial reconstruction of semiarid mediterranean =landscapes for multipurpose land uses. *In*: Allen, E.A. (ed.). *The reconstruction of disturbed arid lands: an ecological approach*. American Academy for the Advancement of Science Selected Symposium 109.

- Pase, C.P. 1981. Community structure analysis-a rapid, effective range condition estimator for semi-arid ranges. *In: H.G. Lund, et al. (tech. coord.). Arid land resource inventories: Developing cost-efficient methods.* USDA Forest Service General Technical Report WO-28, Washington D.C.
- Polley, H.W., H.B. Johnson, B.D. Marino, and H.S. Mayeux. 1993. Increase in C3 plant water-use efficiency and biomass over glacial to present CO₂ concentrations. *Nature* 361:61-64.
- Schlesinger, W.H., J.F. Reynolds, G.L. Cunningham, L.F. Huenneke, W.M. Jarrell, R.A. Virginia and W.G. Whitford. 1990. Biological feedbacks in global desertification. *Science* 247:1043-1048.
- Shakesby, R.A. 1993. The soil erosion bridge: a device for micro-profiling soil surfaces. *Earth Surface Processes and Landforms* 18:823-827.
- Sheridan, D. 1981. Desertification of the United States. Council on Environmental Quality. U.S. Government Publishing Office. Washington D.C.
- Tausch, R.J., P.E. Wigand and J.W. Burkhardt. 1993. Viewpoint: Plant community thresholds, multiple steady states, and multiple successional pathways: legacy of the Quaternary? *Journal of Range Management* 46(5):439-447.
- U.S.D.A. Forest Service. 1993. Watershed management practices for pinyon-juniper ecosystems.
- Watt, A.S. 1947. Pattern and process in the plant community. *Journal of Ecology* 35:1-22.
- West, N.E. 1990. Structure and function of microphytic soil crusts in wildland ecosystems of arid to semi-arid regions. *Advances in Ecological Research* 20:179-223.
- Westoby, M., B. Walker and I. Noy-Meir. 1989. Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* 42(4):266-274.
- Wood, K.M. and N. Javed. 1991. Hydrologic responses to fuelwood harvest and slash disposal on a pinyon-juniper dominated grassland site in the Gila National Forest. *In: Agencies and Science Working for the Future.* New Mexico Water Resources Research Institute, Las Cruces, NM.