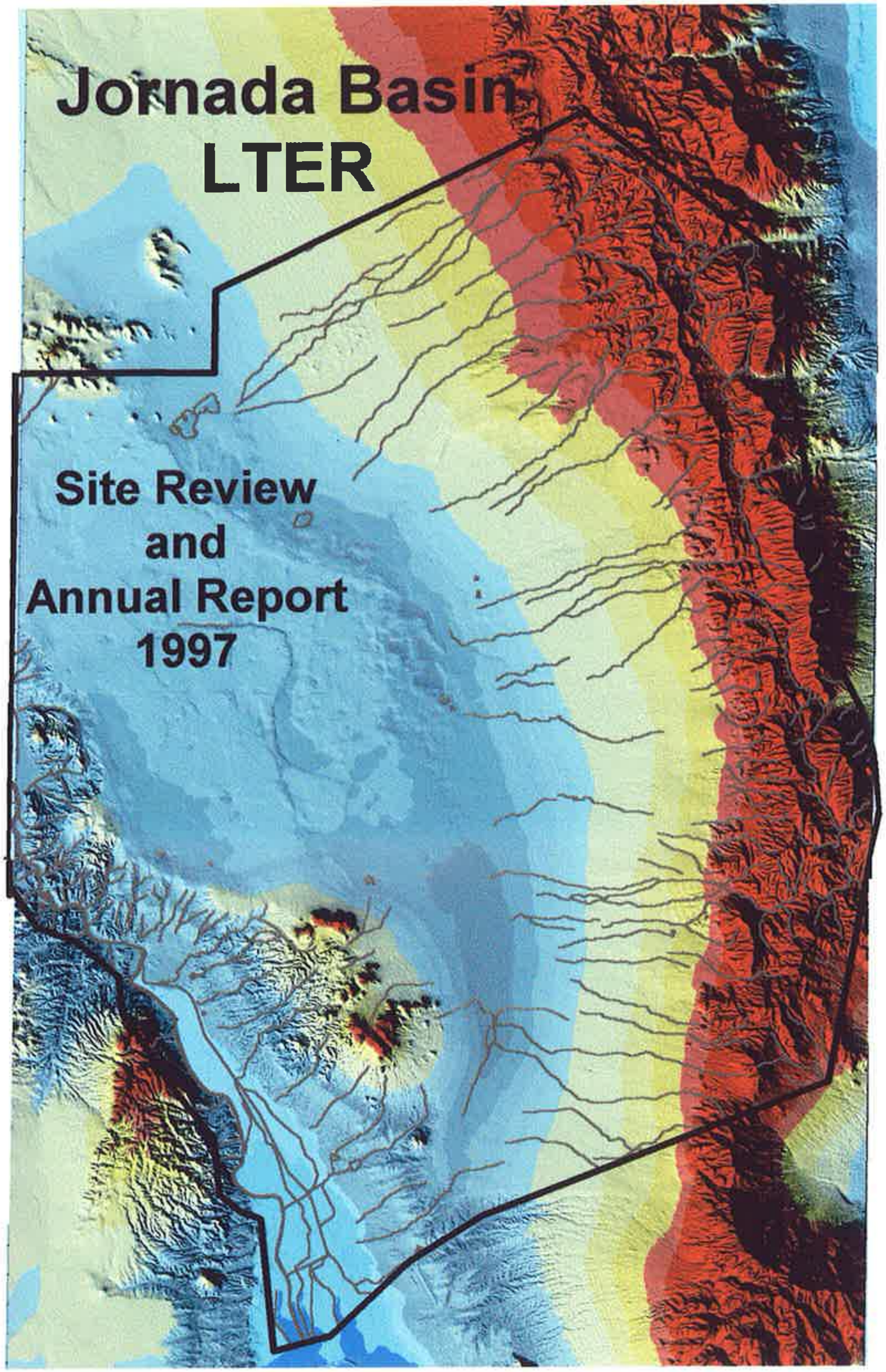
Jornada Basin LTER

Site Review and Annual Report 1997



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Introduction

The Jornada LTER was first conceived in 1981, when a group of scientists from New Mexico State University proposed a program of research to gain a better understanding of the processes that determine the structure and function of Chihuahuan desert ecosystems. Both the group and its mission have evolved with time, but certainly a basic motivation for our studies was the dramatic, historic records of vegetation change in the Jornada Basin. These show a progressive loss of semiarid grasslands dominated by black grama (*Bouteloua eriopoda*) and an invasion of desert shrubland species, predominately creosotebush (*Larrea tridentata*) and mesquite (*Prosopis glandulosa*) (Buffington and Herbel 1965, Figure 1).

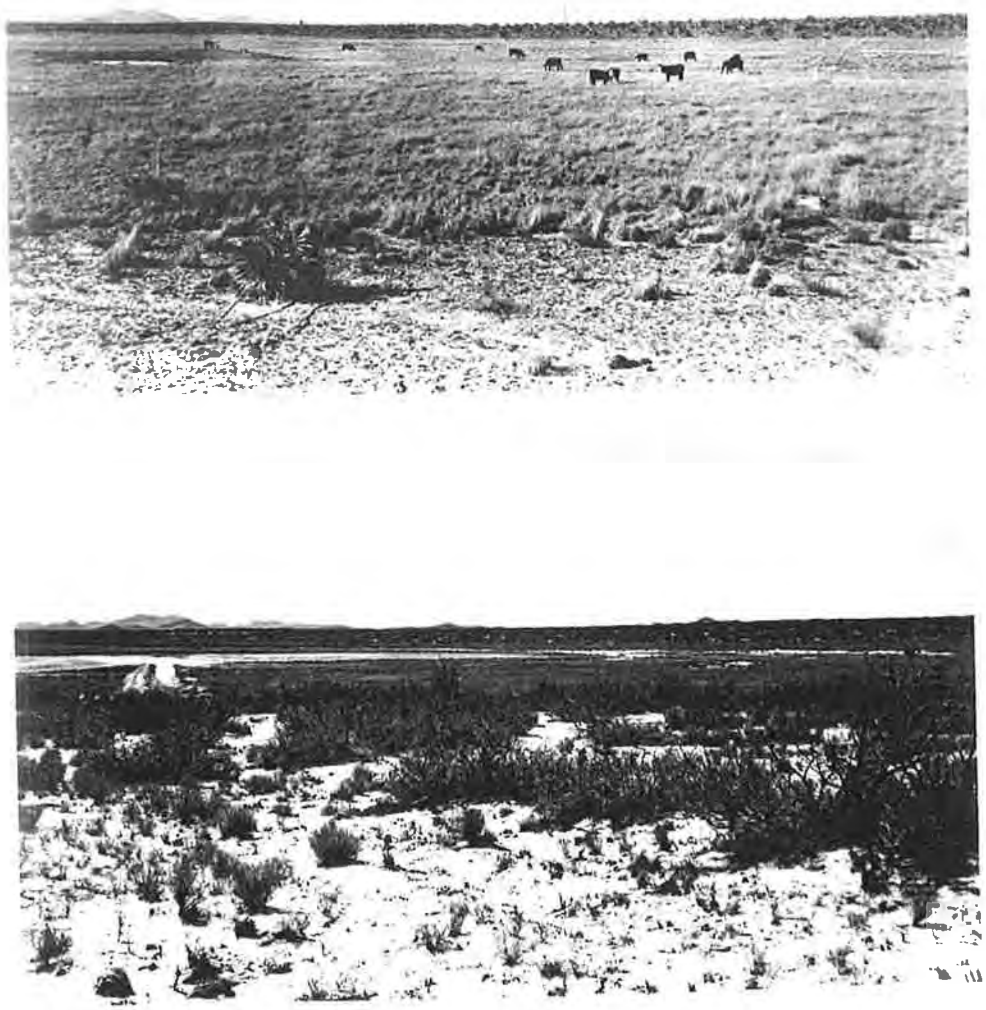

Figure 1. Change in vegetation between 1939 (top) and 1984 (bottom) on the Jornada Experimental Range, looking northeast from approximately one mile west of Red Lake Well. From Sallach (1986).

When we began our work, ecologists were pointing an accusatory figure at the historical cattle industry in southern New Mexico, but in reality there was little formal, mechanistic understanding of what might have caused the complete reconfiguration of vegetation on the Jornada landscape. It was equally possible that fire suppression, rising concentrations of atmospheric carbon dioxide, and changes in the seasonal distribution of rainfall had contributed to the large changes in ecosystem structure and function that had occurred in just a few decades.

It was also likely that an unequivocal answer would not derive from traditional scientific studies and short-term research grants. Many of the plants in question require well over 10 years to establish in new areas, and changes in the seasonal distribution of precipitation, that might lead to changes in vegetation, occur on time scales of decades and longer. Thus, the Jornada Basin was a natural candidate for the Long-Term Ecological Research (LTER) program being organized by the National Science Foundation, and it was funded in the initial cohort of sites established in 1981.

Today, National Science Foundation support for the Jornada LTER is supplemented by cooperative efforts and funding from the USDA's Agricultural Research Service (ARS) and a variety of other Federal agencies (see Appendix "Grants"). The LTER efforts in the Jornada Basin build on the century-long efforts by ARS scientists to understand rangeland conditions in the Jornada Basin and on studies conducted as part of the International Biological Program (IBP) at the Jornada in the early 1970s (Havstad and Schlesinger 1996).

Like all LTER sites, our studies in the Jornada Basin have been organized in 5 core areas (Callahan 1984) to examine:

1. pattern and control of primary production

2. spatial and temporal distribution of populations selected to represent trophic structure

3. pattern and control of organic matter accumulation in surface layers and sediments

4. patterns of inorganic input and movements through soils, groundwater, and surface water

5. pattern and frequency of disturbance to the research site.

Over the past 10 years, we have developed a long-term monitoring program and archival datasets (see tabs "Core Areas" and "Data Management") in each of these areas, to provide a baseline of information regarding the response of the Chihuahuan Desert ecosystem to climatic fluctuations and to regional changes in climate. Research on disturbance is of particular interest: Any insight gained on the role of cattle as a disturbance agent would surely aid the ongoing national effort to reevaluate the impact of grazing on public lands throughout the southwestern United States. In addition, development of remediation technologies for degraded landscapes requires a thorough understanding of the processes associated with disturbance (Herrick et al. 1997).

Beyond our studies of the *causes* of desertification in southern New Mexico, we are also interested in its regional *effects*. Using the Jornada as an example, in a 1990 paper we postulated the role of deserts in determining regional to global characteristics of the Earth's climate and biogeochemistry (Figure 2). Loss of vegetation raises regional albedo, but also, regional air temperatures (Bryant et al. 1990). Barren soils are a source of wind-borne dust, which can affect the radiative balance of the planet depending on the mineralogy of dust and its persistence in the atmosphere (Tegen and Fung 1995). Loss of vegetation lowers the infiltration of soil moisture, leading to higher runoff losses of rainwater, greater losses of soil nutrients, and the persistence of regional desertification (Abrahams et al. 1995). Thus, the LTER studies in the Jornada Basin treat both the cause and effect relationships associated with the shrub invasion of semiarid grassland habitats.

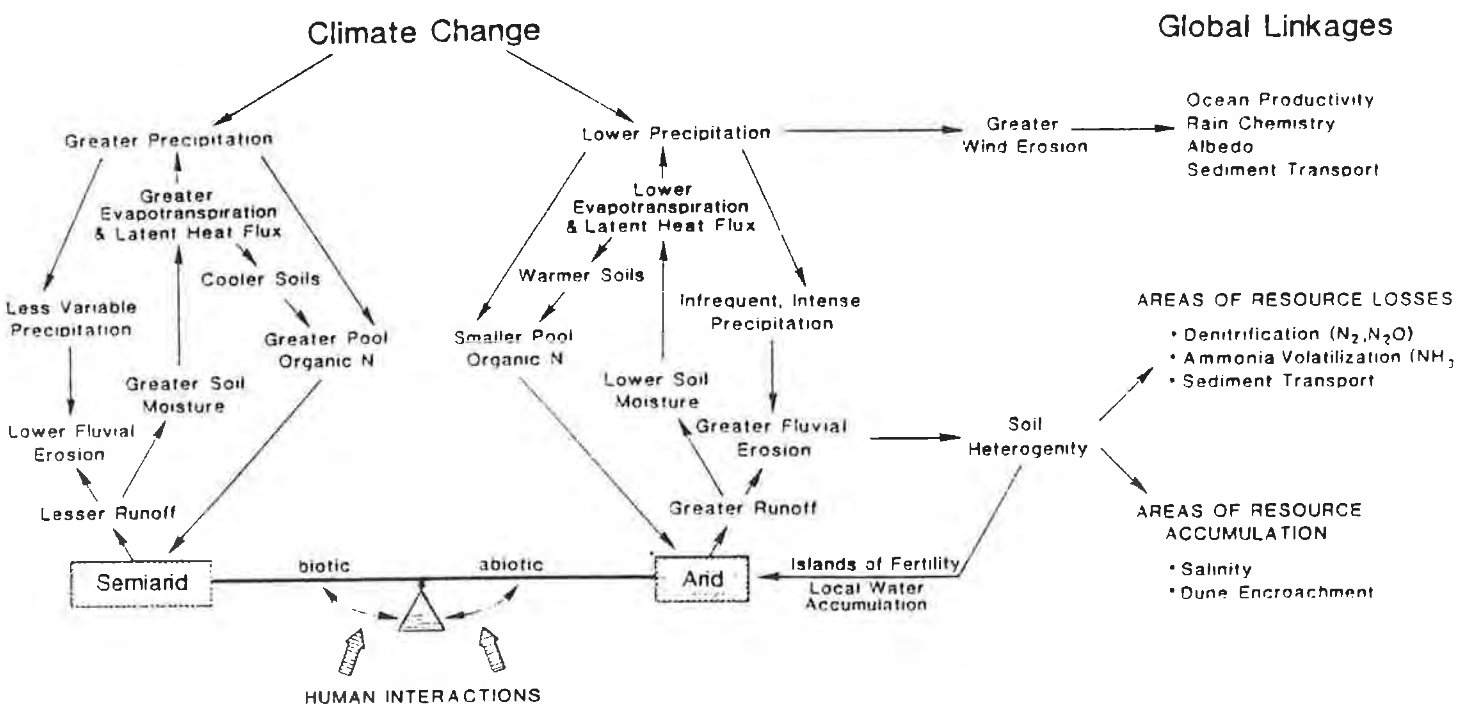

Figure 2. Global feedbacks (right) associated with a shift in vegetation between semiarid grassland and arid-land shrublands, tipped as if a teeter-totter by human activities (bottom) or climate change (Schlesinger et al. 1990; see page 12 under tab "Publications").

The Jornada Basin in the Chihuahuan Desert.

The Chihuahuan Desert is the largest desert in North America. The vast majority of this desert occurs in Mexico, in the States of Chihuahua and Coahuila (Figure 3). The habitats of the Jornada del Muerto Basin are most representative of the northern Chihuahuan desert (the Trans Pecos region) and of the sensitive transition between the short-grass prairie of the central U.S. and the shrub-dominated ecosystems of the Sonoran and Mojave Deserts to the west of the Continental Divide.

The Jornada Basin receives an average of 23 cm/yr of precipitation--about half in monsoonal storms that derive from the Gulf of Mexico during the late summer and the remainder in synoptic weather systems stemming from the Pacific Ocean during the winter months. Rainfall shows large interannual variability

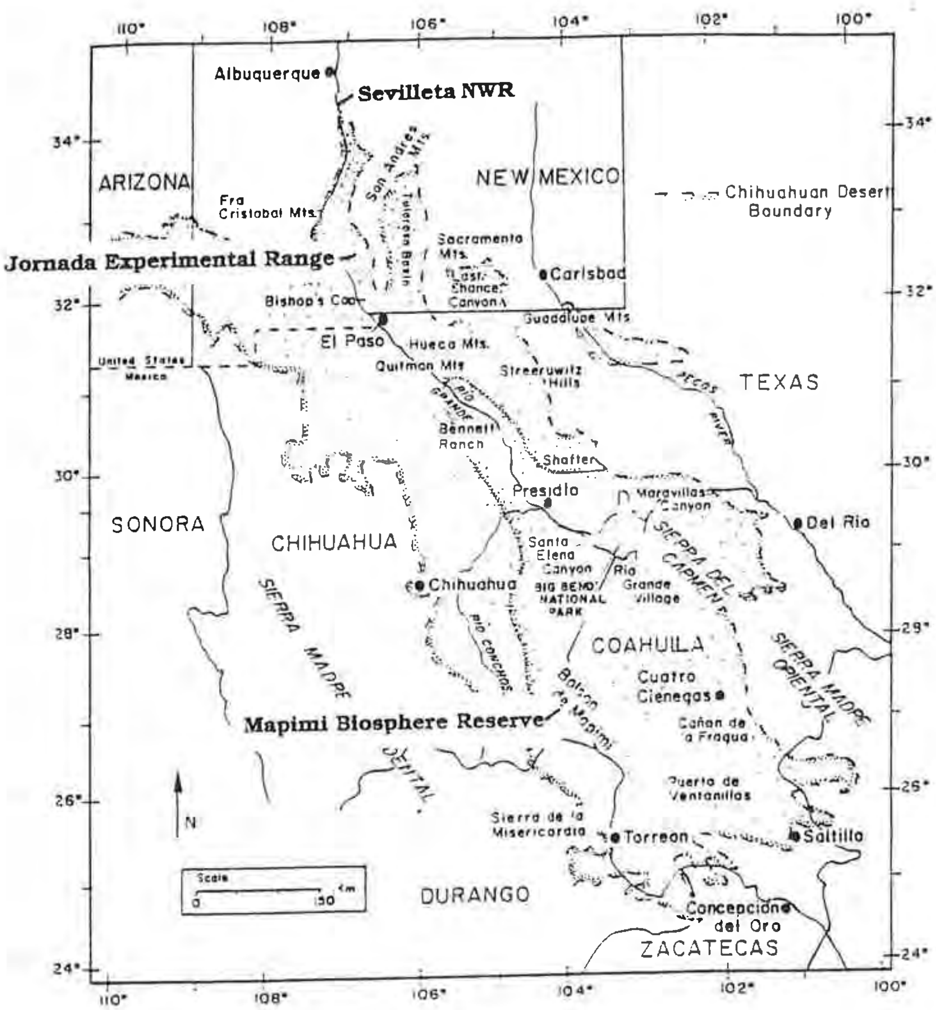

Figure 3. Map of the full extent of the Chihuahuan desert, showing the location of the Jornada Basin. From Van Devender (1990).

that controls the relative growth of C-3 shrubs during the winter and C-4 grasses in summer. Potential evapotranspiration is about 230 cm/yr, so the Bowen ratio--the dissipation of sensible versus latent heat--is very high. During the summer, the mean maximum temperature is 36 C, and often little or no precipitation is recorded in the months of May and June.

The Jornada Basin is typical of the closed-basin topography that is found in many arid regions of the southwestern United States (see cover and Figure 4). Parallel, north-south block-faulted mountains separate individual valleys, which have a predominance of internal drainageways terminating in intermittently flooded lakes, known as playas. In the Jornada basin, soils are largely derived from alluvial deposits from the mountains, as well as from floodplain deposits laid down by an ancient water course of the Rio Grande through the Jornada del Muerto valley. The entire surface is subject to wind erosion and eolian redistribution of soil materials.

When we began our work, existing studies of plant growth showed little difference in the net primary production (NPP) between black grama grasslands and the various shrubland habitats of the Jornada basin. Rather, plant production seemed determined by landscape position--with greater plant growth in areas where runoff water accumulated and lower plant production in areas of limited soil moisture. The similarity of NPP between grassland and shrubland habitats suggested that plant production, *per se*, was not a good index of desertification, to the extent that this term is appropriate to the historical loss of productive semiarid grassland in southern New Mexico.

As an alternative, our research group has focused on changes in the distribution of essential soil resources during the transition from grassland to shrubland habitats. Sampling shrublands at a scale of 10- to 100-cm intervals, we found enormous variation in the content of nitrogen among soil samples. When we sampled grasslands at the same spatial scale, the soil samples seemed rather homogeneous in basic soil characteristics (Schlesinger et al. 1996). Of course, ecologists have long-recognized that patches, or "islands," of fertility gather under shrub vegetation, which leads to a heterogeneous distribution of soil resources in deserts. What was new to our work was that we hypothesized that the desertification of semiarid grasslands may not be so much associated with a change in vegetation production as with an increase in the spatial heterogeneity of soil resources. The heterogeneity of soil resources created by invading shrubs is followed by a further localization of soil resources under shrub canopies promoting the invasion and persistence of shrubs. The patchy distribution of soil resources leads to heterogeneity in the distribution of soil microbial biomass (Herman et al. 1995), nematodes (Freckman and Mankau 1986) and microarthropods (Santos et al. 1978). The patches of soil fertility created by plants (Thompson and Huenneke 1996) and animals (Chew and Whitford 1992) are preferred sites for the establishment of shrubs. Barren areas between shrubs are

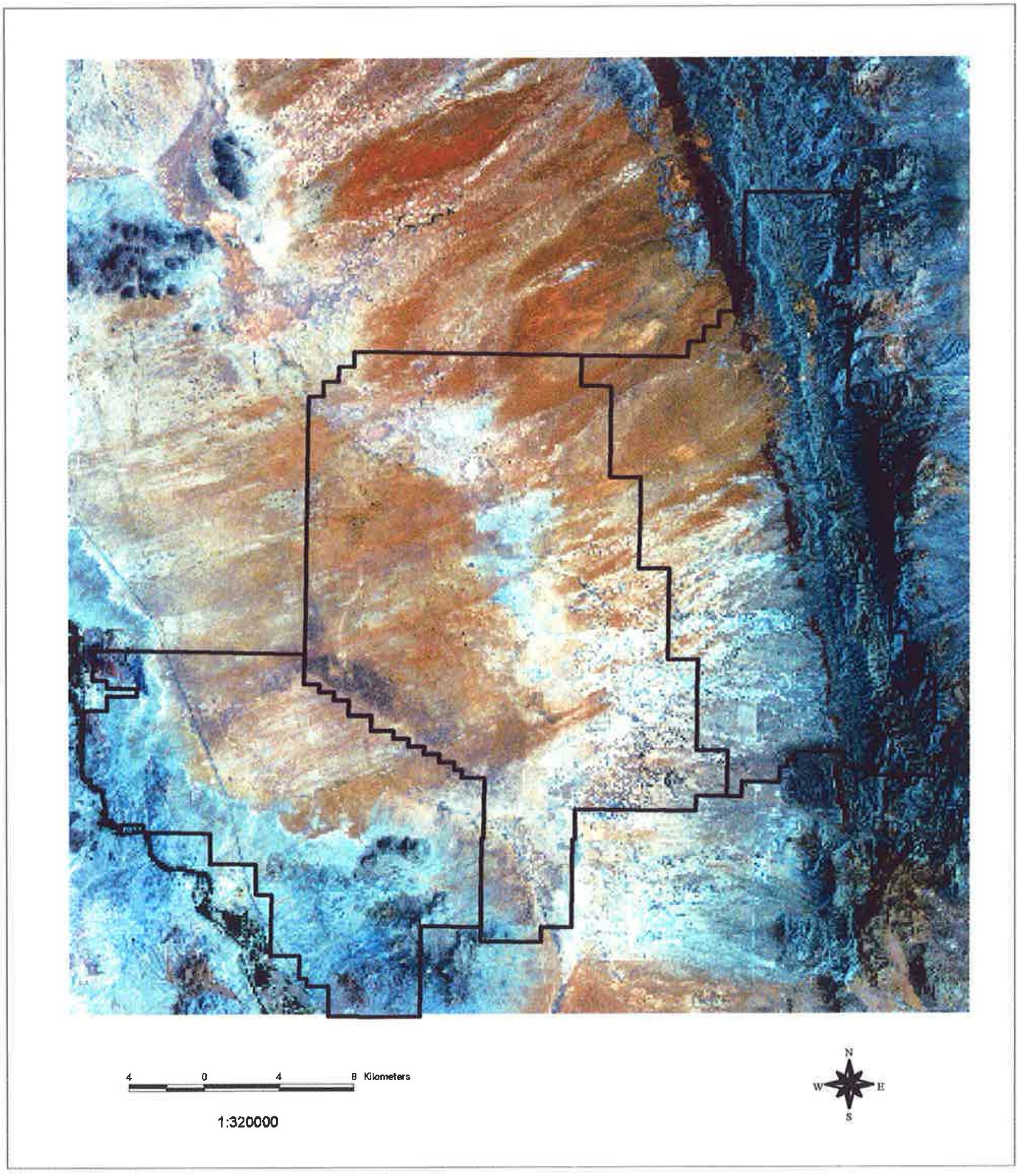

Figure 4. Landsat TM bands 3, 2, 1, June 5, 1995.

increasingly subject to the physical removal of soil resources by water and wind erosion (Figure 5), and the potential for long-term depletion or loss of soil resources.

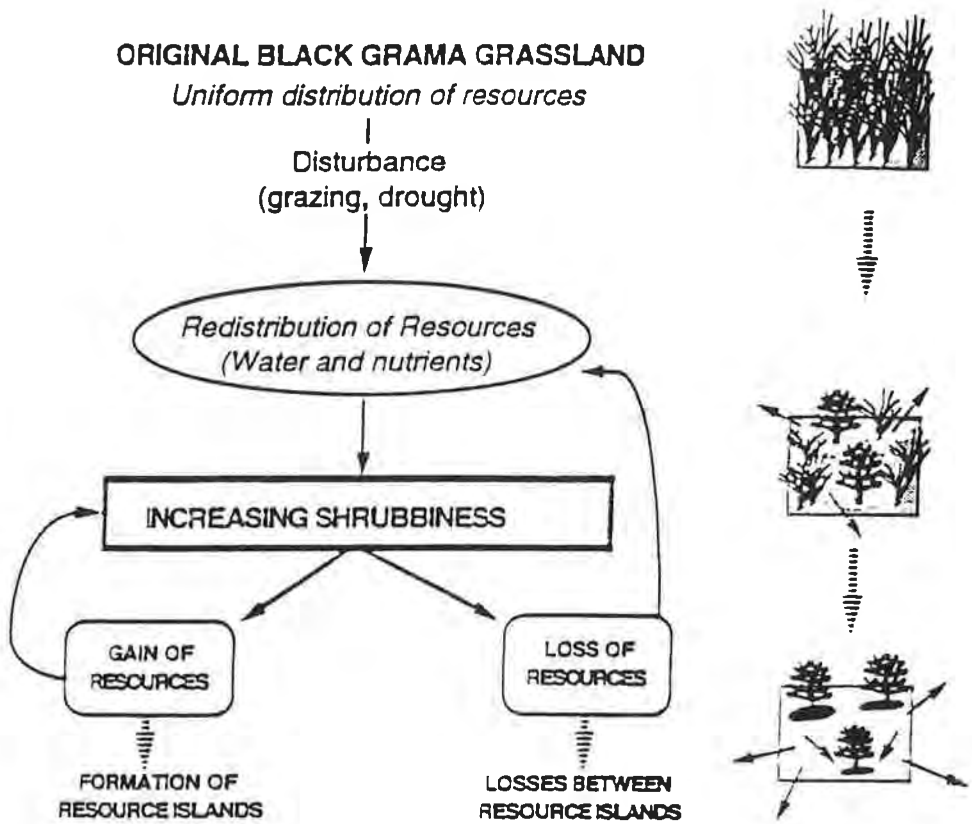

Figure 5. A model of autogenic factors that lead to the development of soil resource heterogeneity and to desertification of semiarid grasslands.

Desertification.

Drought is certainly linked to the downfall of great historic civilizations, including the early Mesopotamian civilization in 2200 B.C. and the Mayan culture in Mexico around 900 A.D. In the future, we can expect that the position of the border between arid and semiarid lands will be one of the most sensitive indices of global climate change, which may include a transient period of widespread drought during the next century.

Throughout the world, lands at the border of arid regions are increasingly subject to human impact, leading to degradation of soils, losses of plant production, and a diminished economic potential to support human populations. Focusing on the human impact and consequent losses in economic potential, we often call these changes "desertification". With the potential for global climate change, however, the definition of desertification and its potential must be expanded. The 1992 United Nations Desertification Convention defined desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities."

Even this definition will be problematic. Desertification should not be used to describe cyclic phenomena, as when decadal variations of precipitation lead to periods of drought and to losses of vegetation cover that are fully restored when the rains return. Indeed, Tucker et al. (1994) showed that most of the southward expansion of the Sahara desert in the early 1980s was effectively reversed with a return to a period of greater rainfall later in that decade.

The Chihuahuan Desert dates to about 9,000 years ago. It has been hypothesized that during the last 3,000 years there have been three transitions between grasslands and shrublands, each followed by a return of grasslands in southern New Mexico (Van Devender 1995). Today, perennial bunchgrasses, such as black grama, may represent a relictual community from more mesic climatic conditions in the mid-Holocene. Some modern plant species endemic to the desert were certainly present when large herbivores, such as ground sloths and mammoths grazed the Chihuahuan desert, but apparently this region has never been subject to high levels of herbivory by bison and other native ungulates for the past 10,000 years (Mack and Thompson 1982).

We believe that the changes in ecosystem structure and function in southern New Mexico may represent an ongoing desertification process that is driven by human impact. When subjected to high levels of cattle grazing in the late 1800s, the grassland ecosystems appear to have shifted to an alternate stable-state, in which shrub vegetation is dominant (Laycock 1991). The shift is likely to have been aided by a decline in the proportion of summer precipitation, which favors the C-4 perennial grasses, in favor of winter precipitation, which favors shrubs (Neilson 1986). This shift may reflect an increasing frequency of Pacific El Nino events, which enhance synoptic wintertime rainfall in the southwestern U.S (Redmond and Koch 1991). Certainly, fire suppression, which aids the establishment of shrub seedlings (Humphrey 1958), and rising CO_2, which benefits the photosynthesis of C-3 shrubs (Idso 1992; but see also, Archer et al. 1995), also may have aided the transition from grassland to shrubland.

We consider all of these factors as allogenic--acting from outside the ecosystem to cause changes in the structure and function of the Chihuahuan desert. The allogenic factors are reinforced by autogenic factors, including the development of soil heterogeneity and islands of fertility, which act internally to reinforce the invasion and persistence of shrubs in the ecosystem (Reynolds et al. 1997).

Socio-economic Factors in Future Environments.

High rates of human population growth, low per capita income, and land-use changes driven by an increasing globalization of the world's economy will impact natural ecosystems in most semiarid environments throughout the world. Nowhere is this better seen than in the nightly news from Sahelian Africa, but similar socioeconomic factors have the potential to cause dramatic changes in the ecosystems of the Chihuahuan desert. In southern New Mexico, for example, the population of Dona Ana county will grow by nearly 40% in the decade of the 1990s (Peach and Williams, 1997). Similar, high rates of population growth are found throughout much of the Chihuahuan desert in Mexico.

In addition to the direct space needed for human occupancy, the infrastructure needed to support this population will have widespread impacts on desert ecosystems, which will be increasingly traversed by roads, powerlines, and aqueducts. In construction activity, humans leave barren soils subject to wind erosion, reroute and linearize natural drainageways, and replace native arid-land vegetation with more profligate users of water.

Although socioeconomic studies have not been the explicit focus of most LTER programs, increasingly we see our studies expanding to include comparisons of human impact in the cross-border region of U.S. and Mexico. Within this region, it is increasingly important that we develop the knowledge and technologies for mitigating the impacts to desert environments and for improving environmental conditions for the increasing human population that lives there. An understanding of basic ecological processes of desert ecosystems must form the basis of management and remediation techniques. Predicting how the natural ecosystems of southern New Mexico will respond to human impacts is a critical goal for our future research.

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Patterns of Net Primary Productivity in Jornada Ecosystems
Laura Huenneke

Our observations confirm a patchiness of plant distribution in these semi-arid ecosystems that is not adequately described by averages (Figure 1). Mean aboveground biomass (g m^{-2}) ranged from 100-300 g m^{-2} for most ecosystems in most seasons; variation within an ecosystem type is substantial enough that in most seasons there are no detectable differences among ecosystem types. That is, mean biomass differed significantly among ecosystems (ANOVA, $p < 0.05$) in only 3 seasons of the first 11 sampled. In contrast, variation among quadrats within a site (i.e., spatial heterogeneity of biomass) does differ among ecosystem types. Interquartile ranges of quadrat biomass values (a conservative index of variation) differed significantly among ecosystem types in 8 of the first 11 seasons (ANOVA, all $p < 0.03$). The grasslands and playas demonstrated lower variation than the shrub-dominated systems.

Aboveground net primary production (ANPP), averaged across all quadrats in a site, is rather low in most years. Annual totals (mean production per site, summed for 3 intervals per year) range from < 10 g m^{-2} yr^{-1} to > 400 g m^{-2} yr^{-1}. Again, variation among sites within an ecosystem type is sufficient that for most intervals there are no significant differences in ANPP among ecosystem types (ANOVA, $p< 0.05$ for only 1 of the first 10 intervals measured). Interestingly, ANPP demonstrates far less heterogeneity among quadrats in a site than does aboveground biomass. Productivity values for individual quadrats within a site showed significant differences in interquartile ranges among ecosystem types in only 1 interval of the first 10; that is, spatial variation in NPP values within sites did not differ significantly among plant communities. Apparently large shrubs and/or succulents create patches with high biomass in shrublands, resulting in spatial heterogeneity, but productivity in those high-biomass quadrats is not sufficiently higher than that of other quadrats to cause equivalent patchiness in production. Hence the patchiness of soil resources, and of vegetation, is not matched by localization of NPP.

The time series of NPP data (1989 - present) is now approaching a length where it is reasonable to examine temporal patterns. Inspection of the first 5 years confirm that aboveground production is seasonal in the Chihuahuan desert climate but that seasonality varies among ecosystem types (Figure 2). Creosote bush sites regularly show peak production in the spring interval (Feb - May); grasslands typically have highest production in the fall (May - Sept) but may have high productivity in other seasons as well. Temporal patterns of productivity are positively correlated among sites in the creosote bush and in the mesquite ecosystem types; that is, all 3 creosote bush sites show synchronous patterns of high or low production. However, grasslands, playas, and tarbush sites are more variable and do not show significant correlation of patterns.

These studies are yielding insights into the community structure of semi-arid vegetation. The grasslands are consistently the most species-rich of the sites, both at a given date and cumulatively over time (Figure 3), while mesquite communities are the most species-poor. Virtually all plants found in creosote bush and mesquite sites are also found in grasslands; conversion of grassland to shrubland apparently has been accomplished more by alteration of species' relative abundances, and loss of many grassland species, than by incursion of a new species assemblage. Phenology data suggest considerable differences among growth forms, and among species within a growth form, in timing of reproductive activity and in response to drought (Figure 4). Our long-term Plant Diversity Experiment, initiated in 1995, is designed to test the significance of species and growth form differences for ecosystem function.

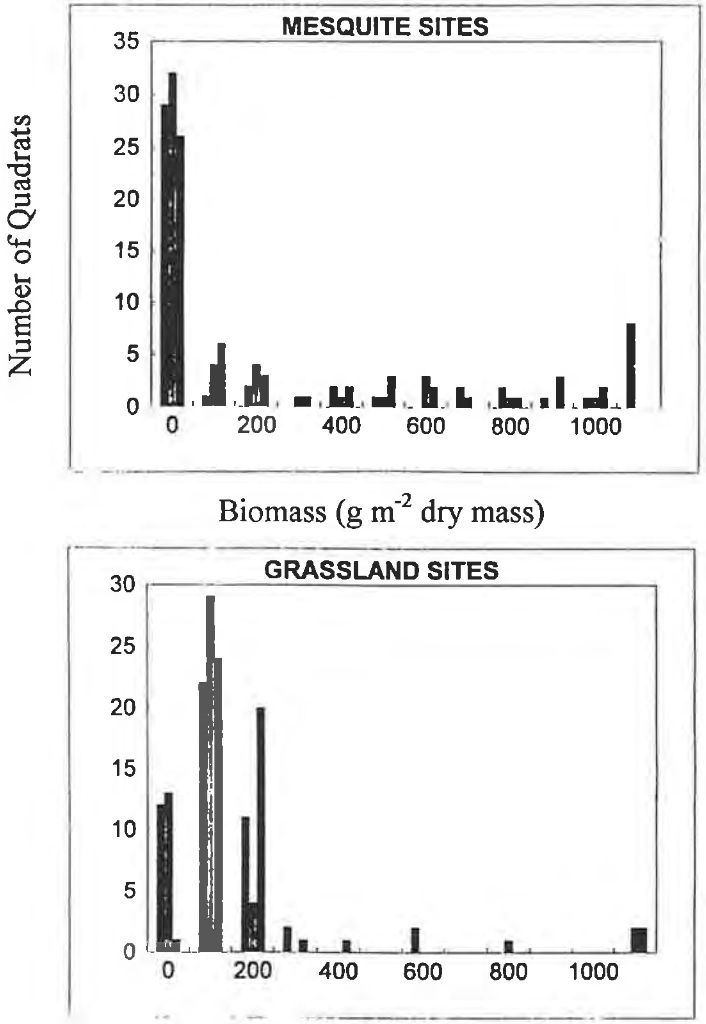


Fig. 1. Frequency distributions of biomass values per quadrat, fall 1991, for 3 sites of each of two ecosystem types.

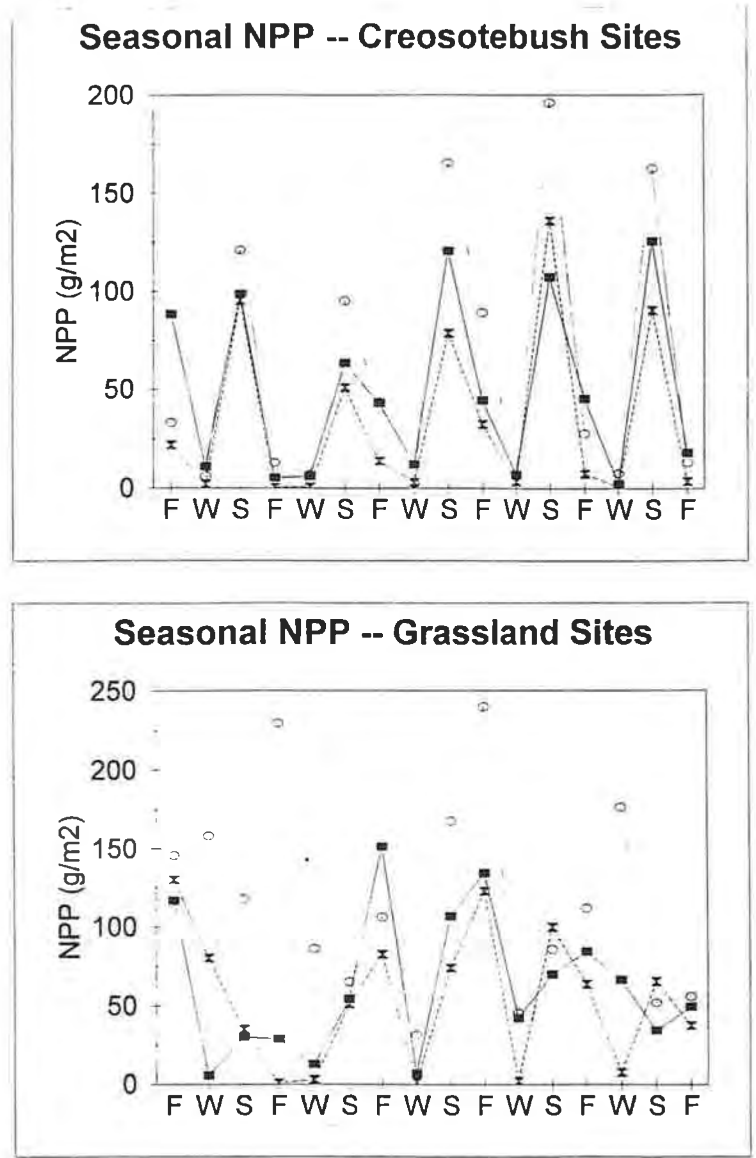
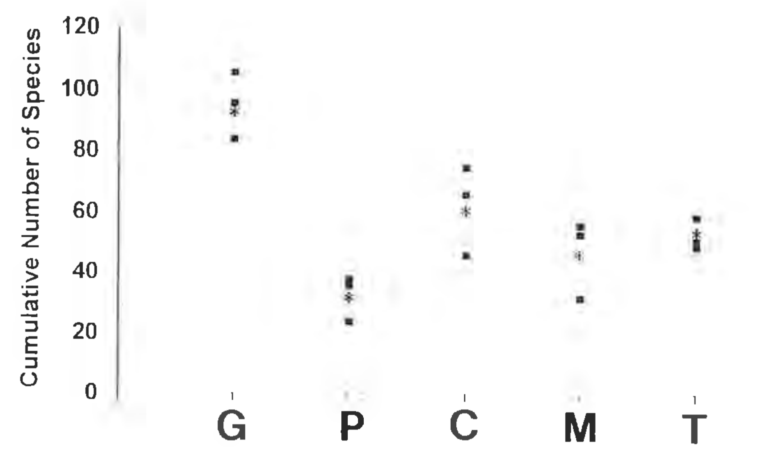


Fig. 2. Seasonal ANPP estimates, 1989 - 1994, for two ecosystem types. F = May - Sept interval, W = Sept - Jan, S = Jan - May.

Fig. 3. Cumulative numbers of plant species encountered per site, May 1989 - May 1996, for 3 sites of each of 5 ecosystem types. G = grasslands, P = playas, C = creosote bush, M = mesquite, T = tarbush. * represents mean of 3 sites.



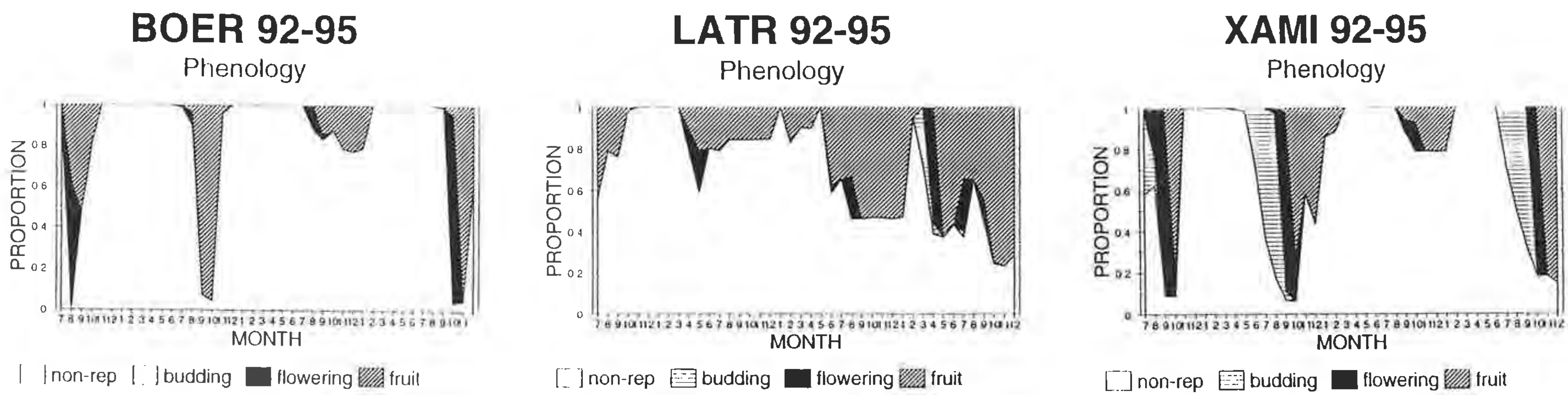


Fig. 4. Reproductive phenology for 3 perennial plant species in Jornada ecosystems. Shaded portions represent fraction of plants in a phenological stage at monthly sample dates from 7-92 to 12-95. BOER = *Bouteloua eriopoda*, LATR = *Larrea tridentata*, XAMI = *Xanthocephalum microcephalum*.

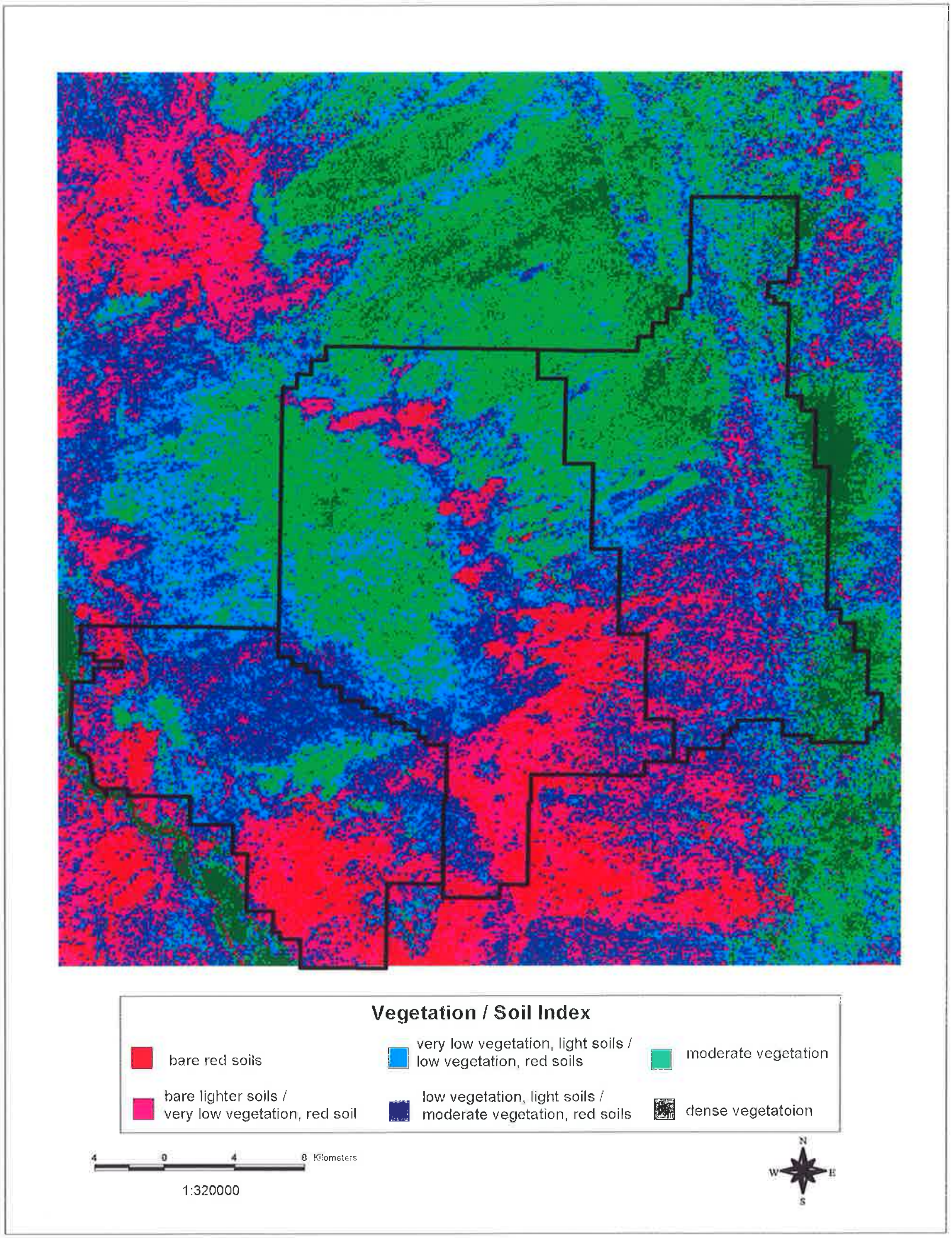


Figure 5. NDVI of Landsat TM scene, June 5, 1995.

JORNADA LTERIII. Animal Consumer Studies.

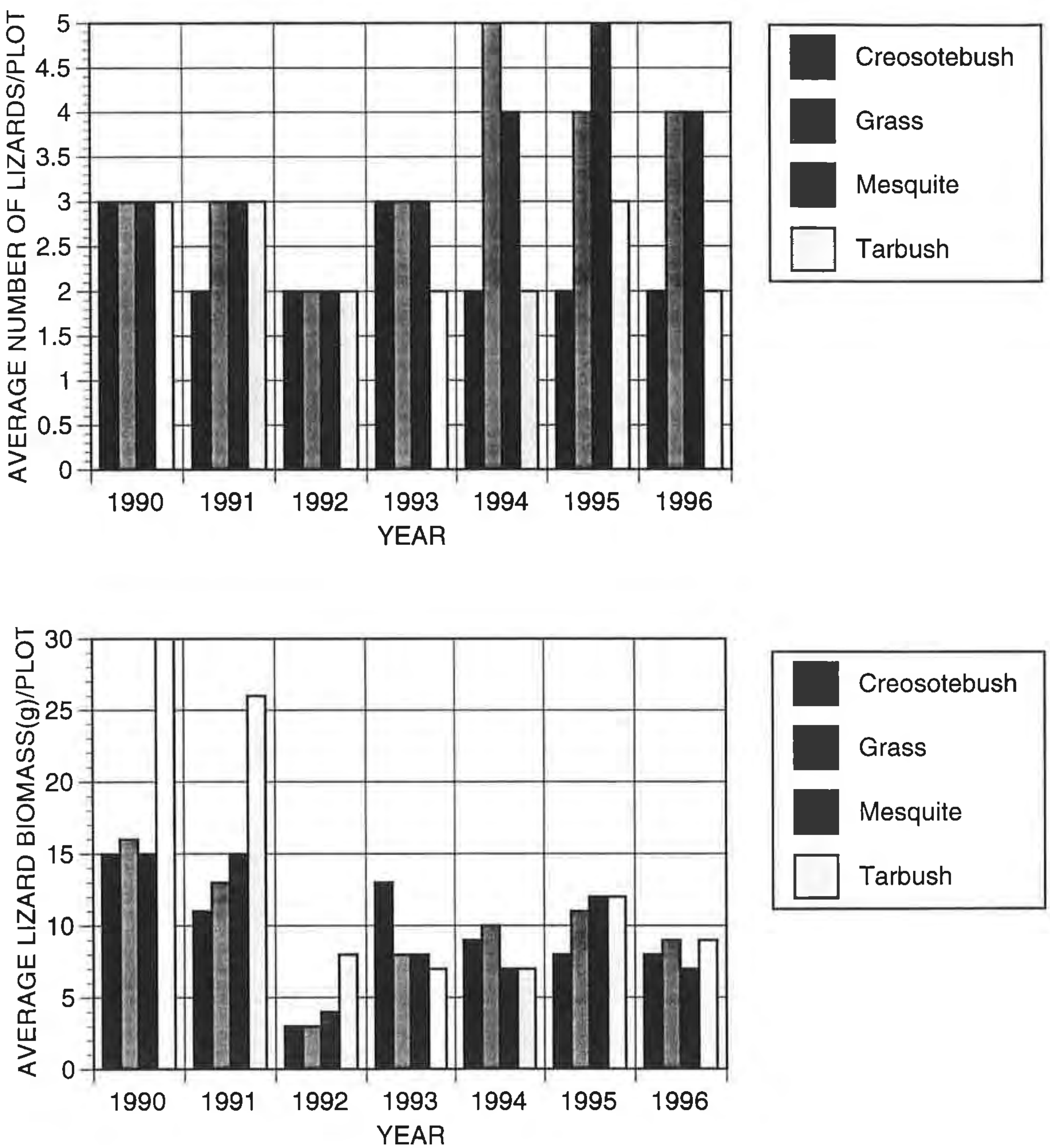
Animal consumer studies continue to focus on how populations and species composition function in desertified and non-desertified Chihuahuan Desert environments. In particular, we are interested in how consumers may be coupled to plant production and precipitation. Additionally, we have initiated a long-term cross-site study to determine how native small mammals influence vegetation, soils, and other consumer groups in Chihuahuan Desert communities and ecosystems.

Ongoing Jornada LTERII consumer studies include monitoring lizard and ground-dwelling arthropod populations, and termite foraging activity, in association with the plant net primary production and rainfall. These studies examine how populations and species composition of major consumer groups in desertified shrub communities (mesquite dune) compare to assemblages in non-desertified grassland and shrubland communities. We are continuing routine measurements of these consumer groups at each of the net primary production study plots.

We have found that populations of consumers vary considerably over time, apparently responding to variation in rainfall and plant production. However, we do not yet see any clear patterns between the response of consumers in desertified habitats compared to less disturbed habitats. Figure 1 illustrates changes in lizard populations among creosotebush, grama grassland, mesquite dune, and tarbush communities over time. Populations and biomass of all lizards fluctuate in similar ways in grass and desertified mesquite habitats, and similarly in creosotebush and tarbush habitats. Lizard populations in grass and mesquite showed the greatest response to the 1992 El nino, with slightly different lag times. Lizard biomass trends were considerably different in tarbush habitats than the other habitat types. Numbers of all lizards were similar across all habitats from 1990-1993, but the tarbush habitats had much higher biomass because a large species of whiptail lizard dominated at the tarbush sites, while smaller side-blotched lizards dominated the other sites. A peak in lizard counts following the 1992 El nino was caused by increases in small side-blotched lizards, and there was very little corresponding change in total lizard biomass over that time. Such overall differences between communities, and between counts and biomass, probably result from different individual species responses to changes in annual rainfall among community types. These results demonstrate that not all species respond to environmental stimuli the same way, and such differences in species responses can greatly affect overall community structure. Ground-dwelling arthropods and termite foraging activity exhibit similar patterns. Such variation in species specific responses compared to overall trophic group responses must be considered for successful ecosystem modeling efforts.

A cross-site study on the effects of rodents and rabbits on Chihuahuan Desert communities was initiated with Jornada LTERIII, utilizing animal exclosure plots. Unlike LTERII consumer studies, this project was designed to determine how an important group of Chihuahuan Desert consumers affect soils and vegetation in grassland and shrubland communities. In particular, we are interested in how these animals may

Figure 1. Average number of lizards and average lizard live biomass sampled from trapping grid plots at the Jornada LTER site from 1990-1996. Averages were calculated from 3 replicate plots/habitat, and 4 sample periods/year.Each plot is 0.6 ha in area.



influence desertification processes, and alter spatial patterns of vegetation and soil structure, as well as biotic community composition. Additionally, we can utilize the monitoring data to see how small mammal populations behave relative to climate fluctuation in grassland and shrubland communities, supplementing the continuing LTERII consumer monitoring studies.

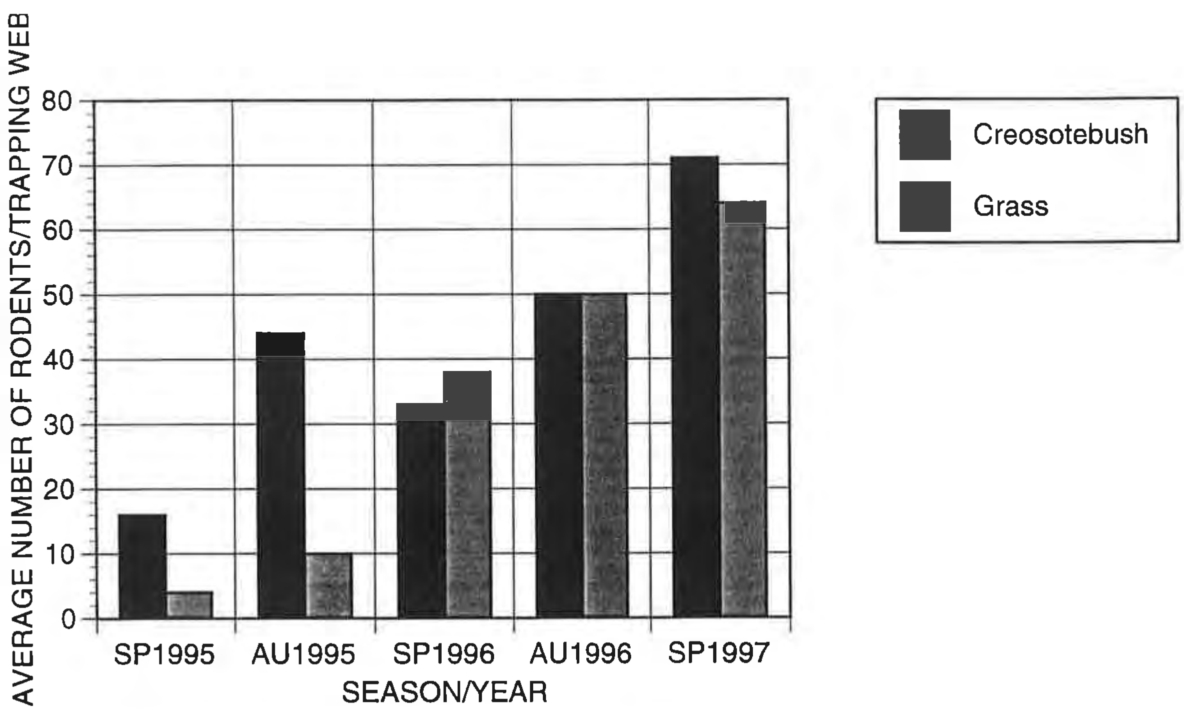
To date we have found that rodent and rabbit populations respond quickly and dramatically to changes and rainfall and plant production, in both grassland and shrubland communities. Figure 2 shows changes in total rodent populations and biomass over the last 2 years. Populations and biomass increased significantly, apparently in response to increased rainfall and plant production in 1996. Rodents in creosotebush and grama grassland showed similar responses, even though the rodent species compositions were very different between those habitats. Note that rodents exhibited a strong response to increased rainfall and plant production in 1996 (Figure 2), while lizards did not (Figure 1). Rodents are homeotherms, are active all year, and are comprised largely of granivores and herbivores. In contrast, lizards are ectotherms, are active only during warm seasons, and are represented entirely by predators. These results demonstrate the importance of examining different consumer groups.

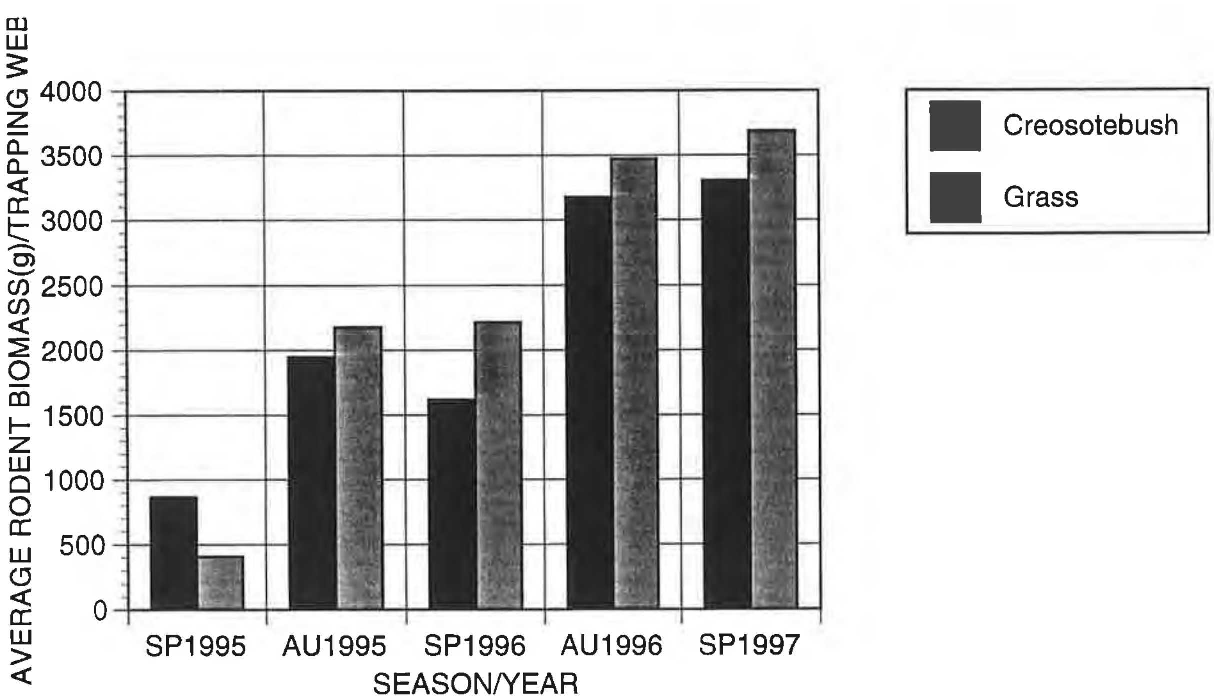
We will probably not find measurable effects of the rodents and rabbits on vegetation for several more years. Based on previous similar research elsewhere, the effects of these animals on desert vegetation and soils will probably be evident in five to ten years from the initiation of the exclosure experiments. In the meantime, this project provides useful monitoring data on important groups of Chihuahuan Desert consumers, including rodents, rabbits, termites, grasshoppers, and ants.

Several student research projects have been recently initiated in association with the cross-site small mammal exclosure study. One Ph.D., one Masters, and two undergraduate REU students are currently conducting comparative research at the Jornada and Sevilleta LTER , and the Mapimi Bioshpere Reserve (Mexico) study sites. Funding for these students has been obtained by supplemental grants to the LTER program.

With the initiation of LTERIII, we have developed two cross-site animal consumer studies. The Chihuahuan Desert small mammal exclosure study includes research sites at Jornada, Sevilleta, and Mapimi, spanning the entire Chihuahuan Desert. Our new arthropod pitfall trap study utilizes the same experimental design and protocols as ongoing arthropod pitfall trap studies at Bandelier National Monument in northern New Mexico, and the Sevilleta LTER site. These cross-site regional studies will provide us with a better understanding of variation in climate and biotic response across entire regions, providing us with a better understanding of how the Jornada ecosystems relate to other ecosystems in the northern Chihuahuan Desert. These cross-site studies have also increased communication and collaboration among researchers at the Jornada, Sevilleta, and Mexican institutions.

Figure 2. Average number of rodents and average rodent live biomass sampled from trapping webs at the Jornada LTER site from 1995-1997. Averages were calculated from 3 replicate webs/habitat. Each trapping web is approximately 3 ha in area.



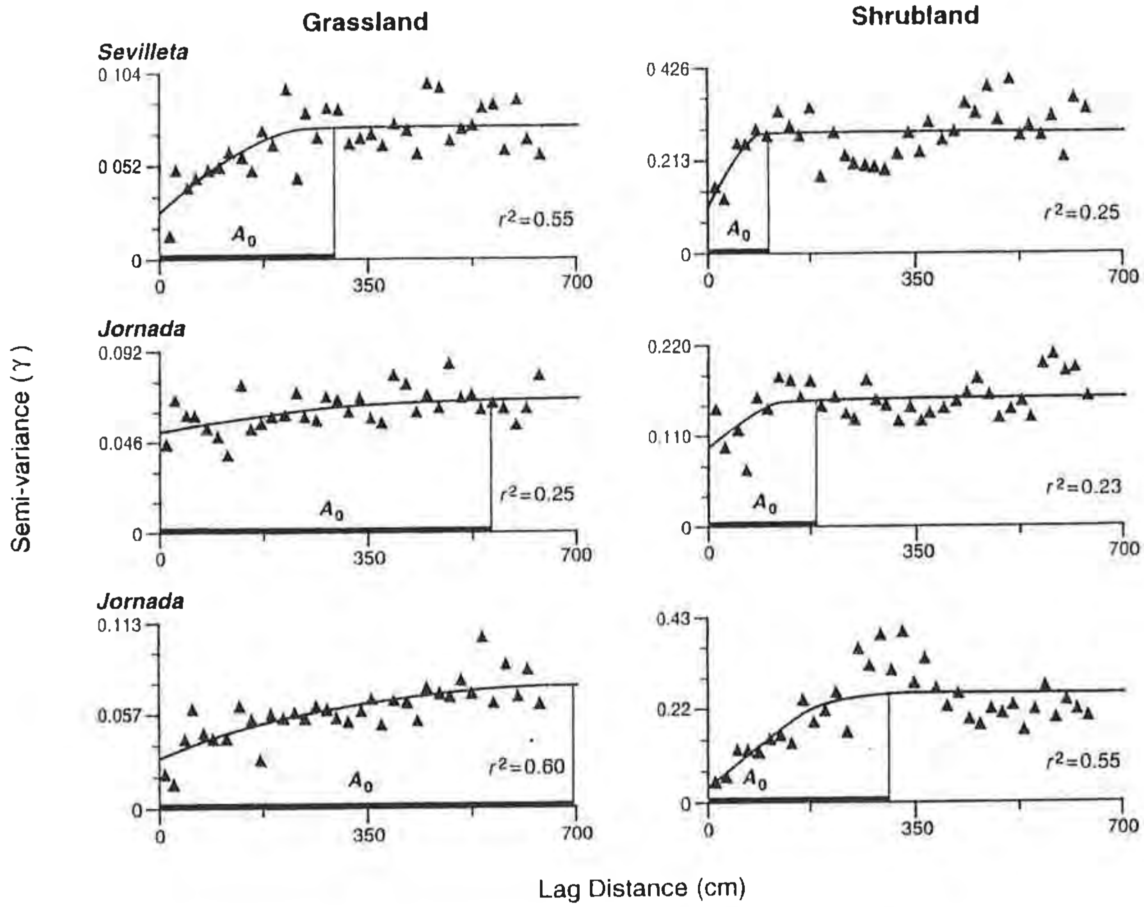


Data from all of these consumer studies should provide us with useful information of how important consumer groups function in northern Chihuahuan Desert ecosystems. We and other researchers may then compare our results to other desert systems to gain a better understanding of consumer roles in desert ecosystems world-wide.

Soil Heterogeneity

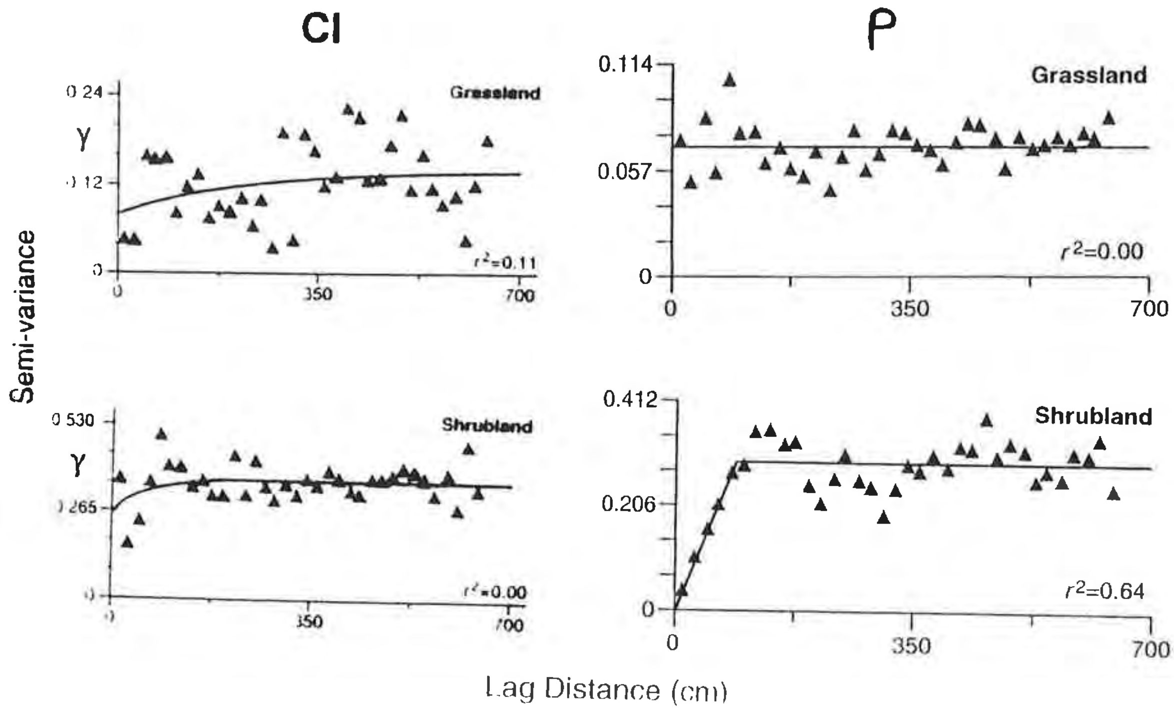
One of the basic tenets that organizes the Jornada's LTER is that desertification is associated with increasing heterogeneity in the spatial distribution of soil resources. Soil samples taken in grasslands are relatively similar to one another, whereas soils taken in shrublands differ strongly depending upon whether a shrub "island" or a barren interspace is sampled.

We have used geostatistics to test this hypothesis in a variety of ecosystems of the arid Southwest--representing a contribution of the Jornada LTER to cross-site studies and comparisons. The distribution of soil nitrogen in grasslands at the Sevilleta and Jornada is autocorrelated over distances of 300 to 700 cm, clearly not associated with the size of the native bunchgrasses (see figure, below). The autocorrelation in creosotebush shrublands extends from 100 to 300 cm, similar to the mean diameter of shrubs in these communities.



Spherical model semivariograms for the distribution of available N in grassland and desert soils at the Sevilleta National Wildlife Refuge (n=1 each) and the Jornada Basin (n=2 each), in the Chihuahuan Desert of New Mexico. The range of spatial autocorrelation is designated as A_O in each panel. From Schlesinger et al. (1996).

The development of spatial heterogeneity of soil nutrients in shrublands is a biotic process--affecting essential nutrients such as N and P much more than mobile, non-essential elements, such as Cl. In grasslands, both Cl and P show a random distribution; in shrublands Cl remains random, while P shows an autocorrelation close to the mean diameter of shrubs (see below). The soil heterogeneity seen in chemical analysis is reflected by a patchy distribution of soil microbial biomass and its activity in shrublands (Gallardo and Schlesinger 1992, Herman et al. 1995).



We have established a long-term monitoring program to examine changes in the spatial distribution of soil nutrients as a result of grazing treatments in the "Stressor" experiments. Specifically, we are making measurements of soil heterogeneity associated with individual shrub islands and at larger, landscape scales by measuring soil properties along transects in mixed grass/shrub systems subjected to grazing, drought, and biodiversity manipulations as part of the joint LTER/EPA Stressor I and Stressor II Experiments.

The LTER/EPA Stressor I Experiment examines the interactions between grazing, drought, fire and other stressors that affect plant function, diversity, and soil properties. We assessed pre-treatment soil variation along three transects located in each of the sixteen 70 x 70 m plots in the Stressor I Experiment, and we are currently analyzing an identical set of soils collected from the Stressor II plots. Baseline soils (approx. 1200 samples total) were collected along each transect in a nested design at spatial scales of 10-m, 1-m, and 0.1-m.

We found that there is no statistically significant variation in total soil N, total carbon, and C/N ration across the experimental plots of Stressor I. In general the coefficient of variation values are low, in the order of about 20-25% for each of the experimental plots. This is typical of the grassland habitats of the Jornada (Schlesinger et al. 1996), and important because it suggests that we will be able to detect changes in the amount of N and its spatial distribution as the experiment progresses. We developed a kriged map of soil N and C for the entire plot (see accompanying figure) on which we can overlay the location of subplots, shrubs, and rodent mounds to examine spatial relationships between soil properties, plants, and animals. An identical analysis is in progress for the Stressor II plots, and the soil analysis will be finished in 1997.

We have also initiated a long-term study of the persistence of shrub-induced spatial variation is soil nutrients beneath mesquite (*Prosopis glandulosa*) and creosotebush (*Larrea tridentata*) in control plots and in adjacent areas that were herbicided in 1972. Our results indicate that the rate at which nutrients are lost or diffuse from the islands to the shrub interspace was different for these species. Once formed these islands are long-term components of desert landscapes. To more directly examine the role of biotic activity associated with shrubs in maintaining the integrity of resource islands, we have also established a long-term experiment within the Stressor II enclosure. Soils were collected at the center of mesquite resources islands and at regular distances extending outward from the canopy to the shrub interspace (see accompanying figure). In addition, stainless steel erosion pins were placed beneath the shrubs to monitor changes in soil movement. After soil sampling, the aboveground shrub biomass was removed by hand for half of the mesquite shrubs while the other shrubs were left as controls. Soils will be collected yearly (this interval will be modified if needed after following initial rates of change in soils) and total C and N, and extractable-P measured. Erosion pins will be measured once or twice a year. This study will quantify the importance of biological and physical processes associated with the presence of the shrub for maintaining the integrity of the resource island. These data will be useful for testing predictions made by the PALS model on the stability of shrub islands following vegetation disturbance.

Figure 1.
Carbon and Nitrogen Distribution Maps Kriged by Variogram Modelling for Stressor I Soils in Jornada–LTER, New Mexico

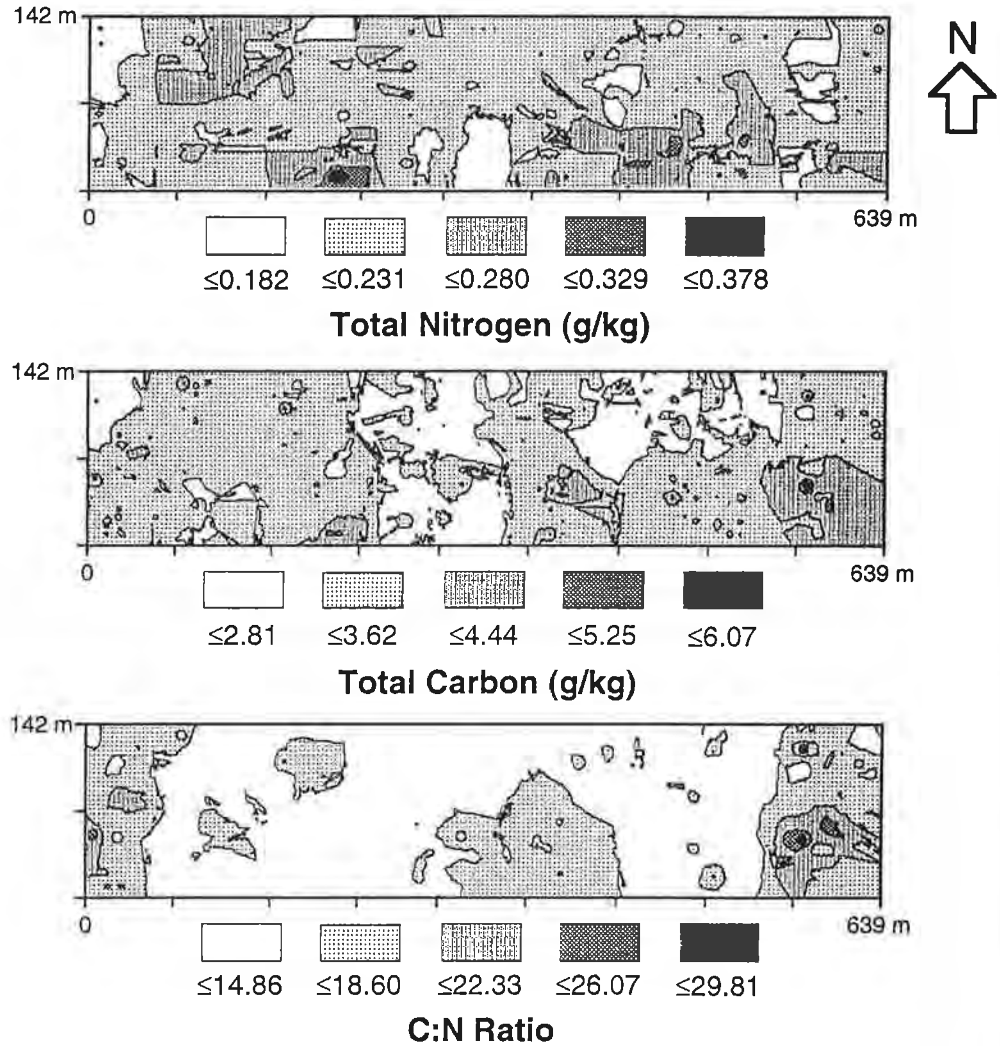
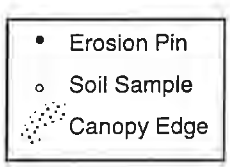
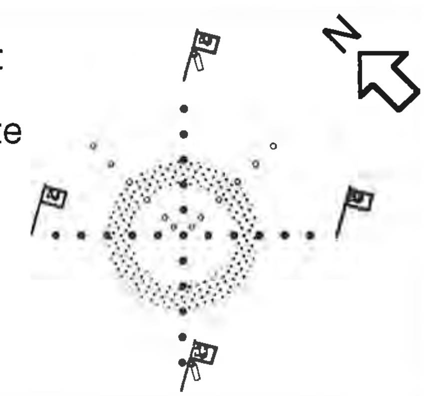


Figure 2.
Setup of Long-term Monitoring Unit for Soil Erosion and Shrub Island Nutrient Dynamics at Stressor II Site in Jornada–LTER, New Mexico





Studies of Hydrologic Transport

Rainfall Simulation Experiments

More than 100 field experiments have been performed on small runoff plots using simulated rainfall. The plots have been either 2 x 1 m or 1 x 1 m in size and the experiments have employed an average rainfall rate of about 140 mm h^{-1} for 30 minutes. The experiments have four goals:

1. To investigate the relative rates and controls of runoff and sediment transport in the grassland and shrubland ecosystems.

2. To evaluate the impact on runoff and sediment transport of digging by small mammals in the grassland and shrubland ecosystems

3. To investigate the relative rates and controls of nitrogen and phosphorus transport in the grassland and shrubland ecosystems.

4. To parameterize the small-watershed and bajada-scale runoff and erosion models.

Runoff and Sediment Yield From Undisturbed Surfaces

Figure 1 shows that the water yields, runoff coefficients, sediment yields, and average sediment concentrations for the simulated rainfall experiments in the grassland and shrubland ecosystems. The water yield and runoff coefficient are 47% and 62%, respectively, higher for the shrubland than for the grassland. However, sediment yields are only 22% higher for the shrubland because the average sediment concentration is 21% lower.

Sediment yield SY is equal to the product of water discharge Q and sediment concentration C. The flow diagrams reproduced in Figure 2 show that in the grassland and under shrubs in the shrubland, the variation in SY is due largely to variation in Q and is not affected by C. In contrast, SY responds to variations in both Q and C in intershrub areas. In the grassland, no significant correlation could be found between Q and the percentage of the runoff plot covered by fines, gravel, litter, or vegetation. On the other hand, Q is negatively correlated with percent vegetation in both the shrub and intershrub areas and with percent litter in the intershub areas. This is a reasonable result, as ground vegetation and litter might be expected to reduce soil detachment by raindrop impact and obstruct soil removal by overland flow.

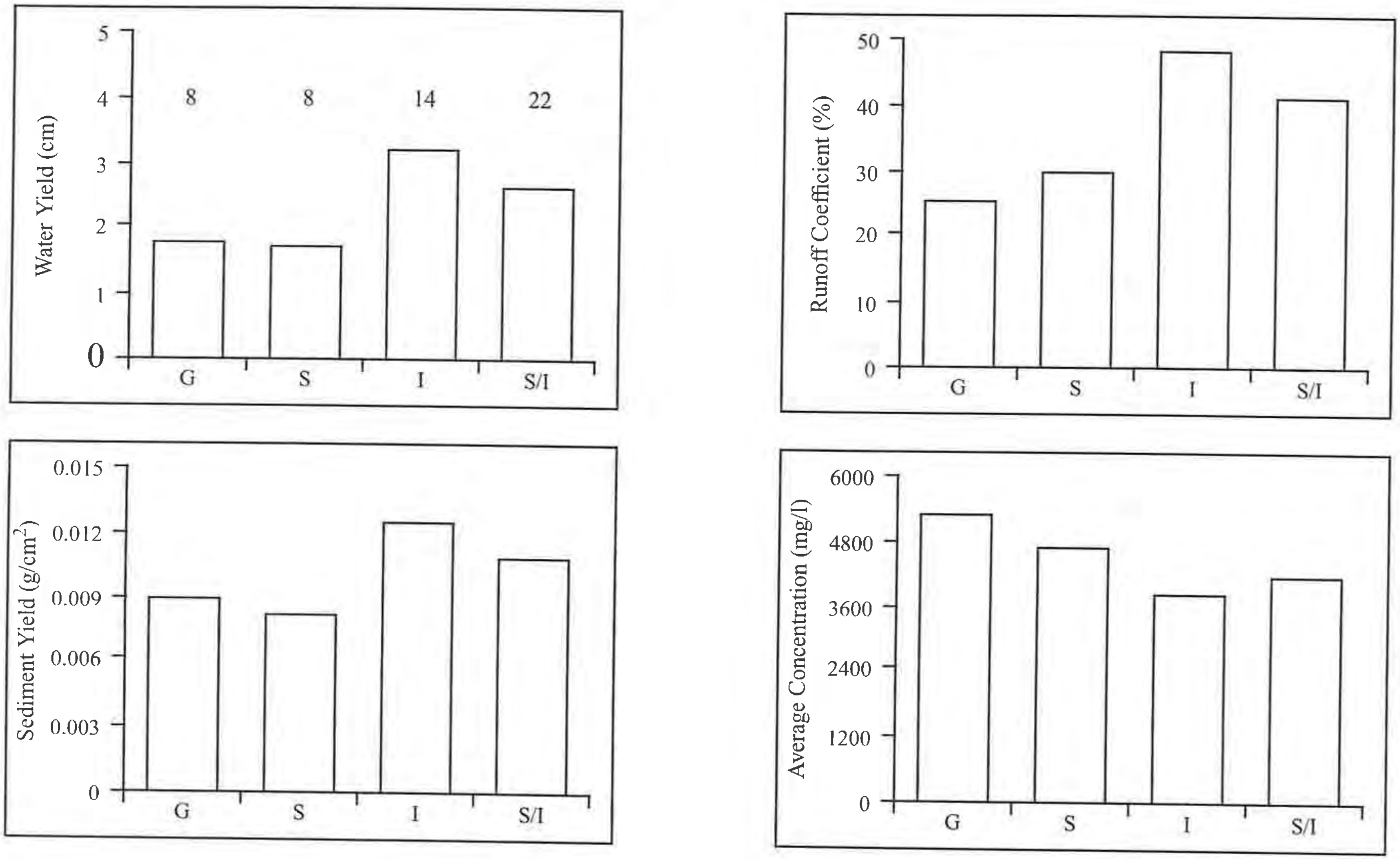


Figure 1. Water yields, runoff coefficients, sediment yields, and average concentrations for 30-minute rainfall simulation experiments on undisturbed plots. G = Grassland, S/I = Shrubland, S = Shrubs, and I = Intershrub areas.

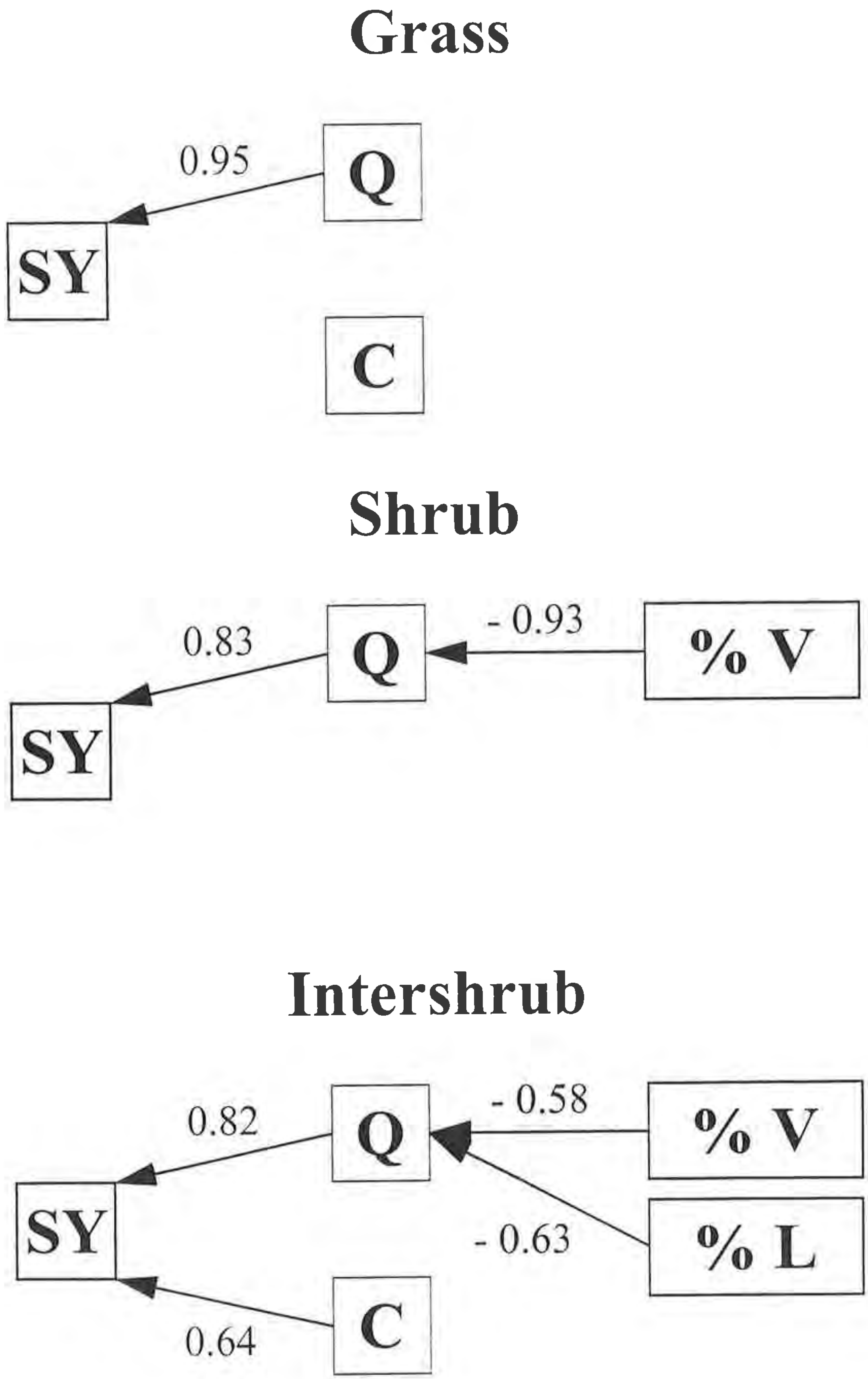


Figure 2. Flow diagrams showing controls of sediment yield from undisturbed grassland, shrub, and intershrub plots.

Runoff and Sediment Yield From Disturbed Surfaces

Figure 3 compares the water yields and sediment yields for disturbed and undisturbed plots in the grassland and shrubland. Digging by small mammals (e.g., rabbits, kangaroo rats, and pack rats) evidently decreases the runoff and increases sediment yield in both ecosystems. The animals break the surface crust, which promotes infiltration, and disperse fine sediment over the ground surface, which enhances soil erosion.

The flow diagrams in Figure 4 show that, as on the undisturbed plots, SY is controlled only by Q in the grassland and under shrubs. In contrast, in the intershrub areas SY responds to variations in both Q and C. Q is negatively correlated with vegetation cover in the grasland and is positively correlated with the proportion of the surface under shrubs that is covered with fines.

The index of disturbance used in this study is:

the number of sample points in a plot where a disturbance was recorded x the diameter of the disturbance at each point x the distance form the top of the plot.

The rationale behind this definition is that sediment yield might be expected to increase as the proportion of the plot disturbed by digging increases, as the size of the disturbances increases, and as the proximity of the disturbance to the plot outlet increases.

Although Figure 3 suggests that disturbance reduces water yield, the disturbance index does not correlate with Q in any of the flow diagrams. Instead the disturbance index correlates positively with C and then only in the case of the intershrub areas; C, in turn, correlates positively with SY.

Nitrogen and Phosphorus Yields From Undisturbed Surfaces

Figure 5 shows that both nitrogen (N) and phosphorus (P) yields are much lower for the shrubland than for the grassland. The flow diagrams in Figure 6 indicate that nitrogen yield (NY) is controlled by Q in the grassland and under shrubs in the shrubland, whereas it is controlled by both Q and C in intershrub areas. In both the shrub and interhrub areas, Q is positively correlated with the percent fines. On the other hand, in the intershrub areas C is negatively correlated with percent gravel, which probably reflects a positive correlation with percent vegetation plus litter, as N is dominated by organic N.

Figure 7 contains the flow diagrams for P. No diagram was prepared for shrubs, as the sample size was too small. In the grassland, variations in phosphorus yield (PY) are determined by variations in Q, whereas in intershrub areas they are determined by variations in C. Neither Q nor C correlated with any surface property.

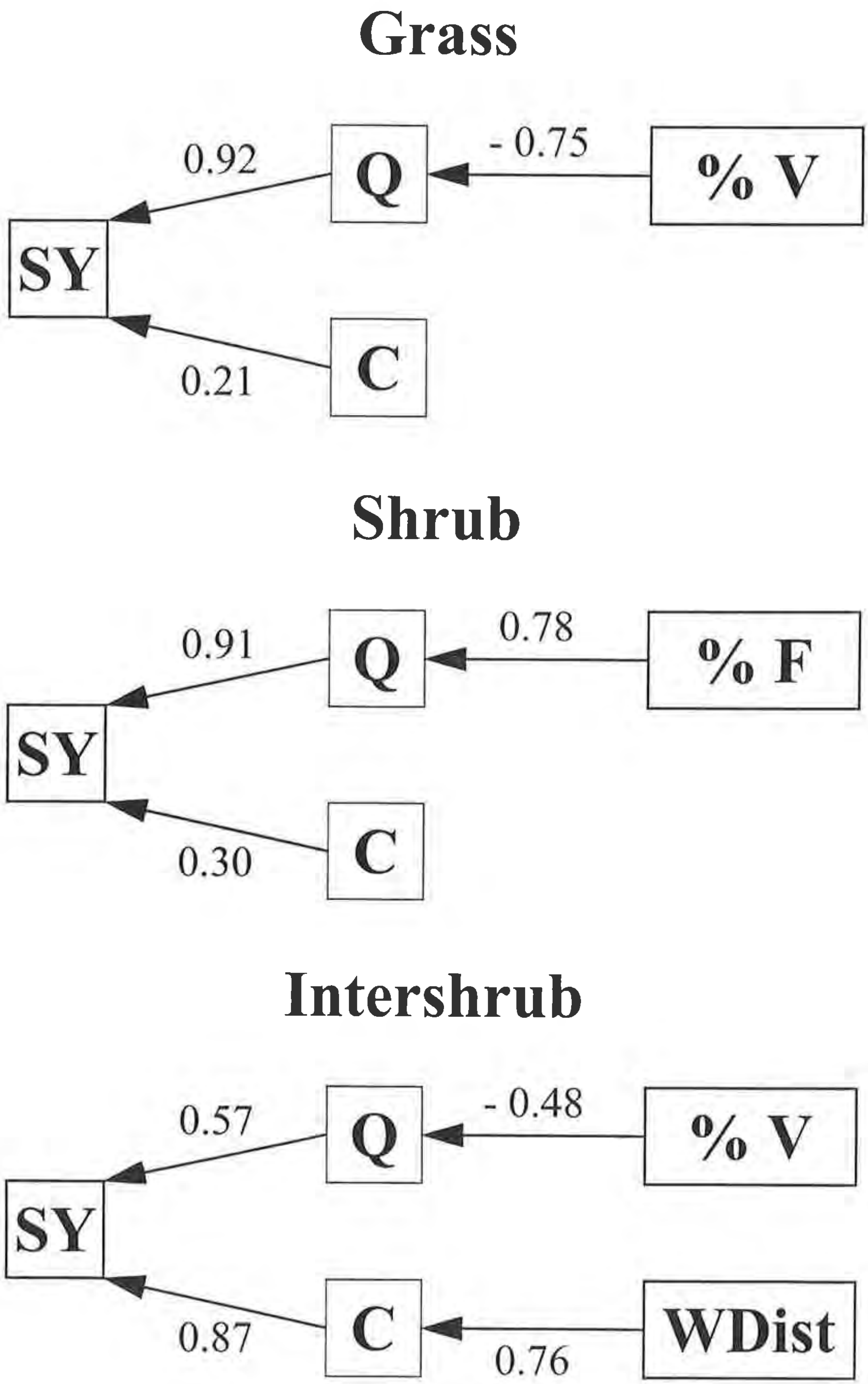


Figure 4. Flow diagrams showing controls of sediment yield from disturbed grassland, shrub, and intershrub plots.

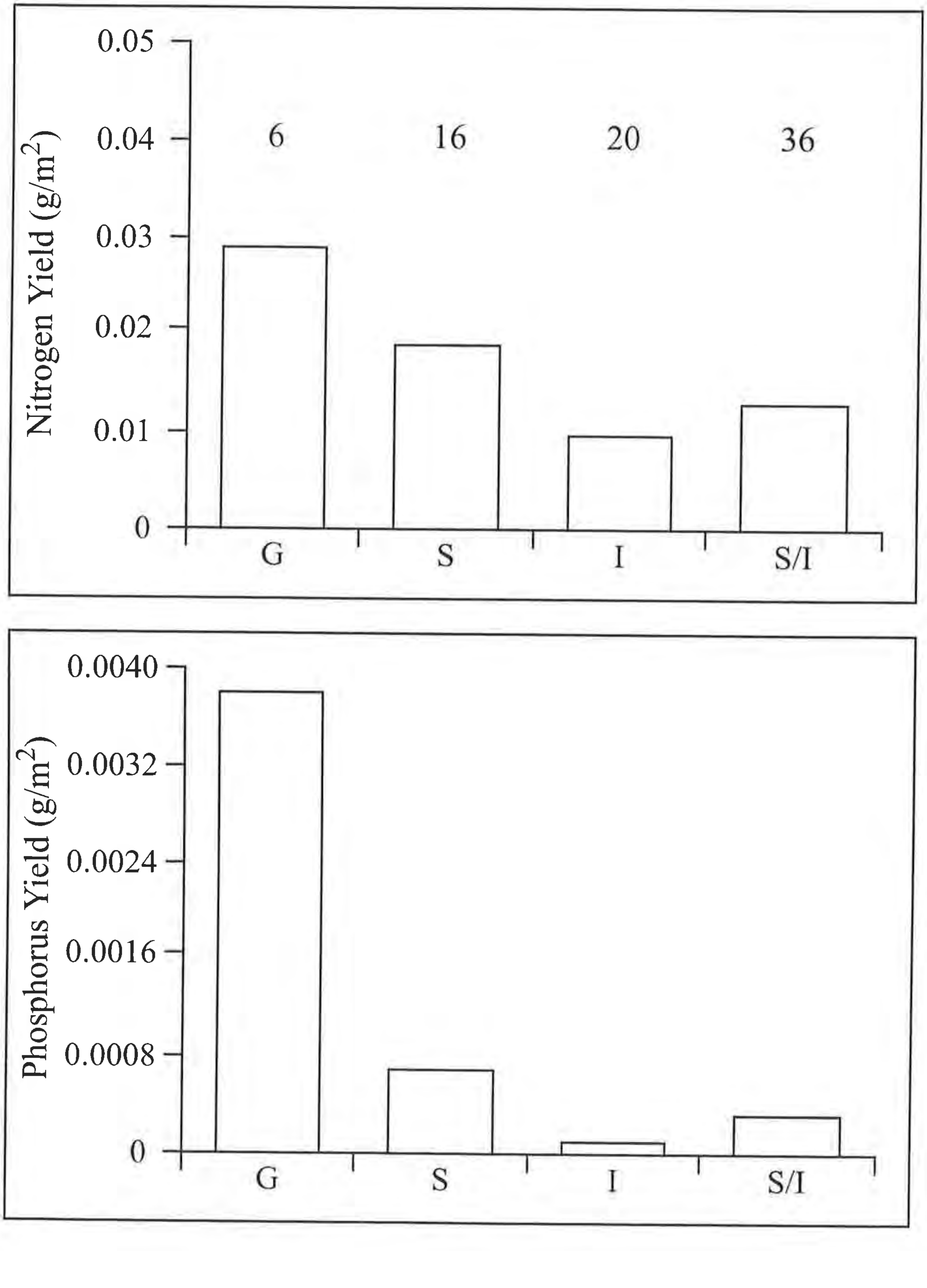


Figure 5. Nitrogen yields and phosphorus yields for 30-minute rainfall simulation experiments. G = Grassland, S/I = Shrubland, S = Shrubs, and I = Intershrub areas.

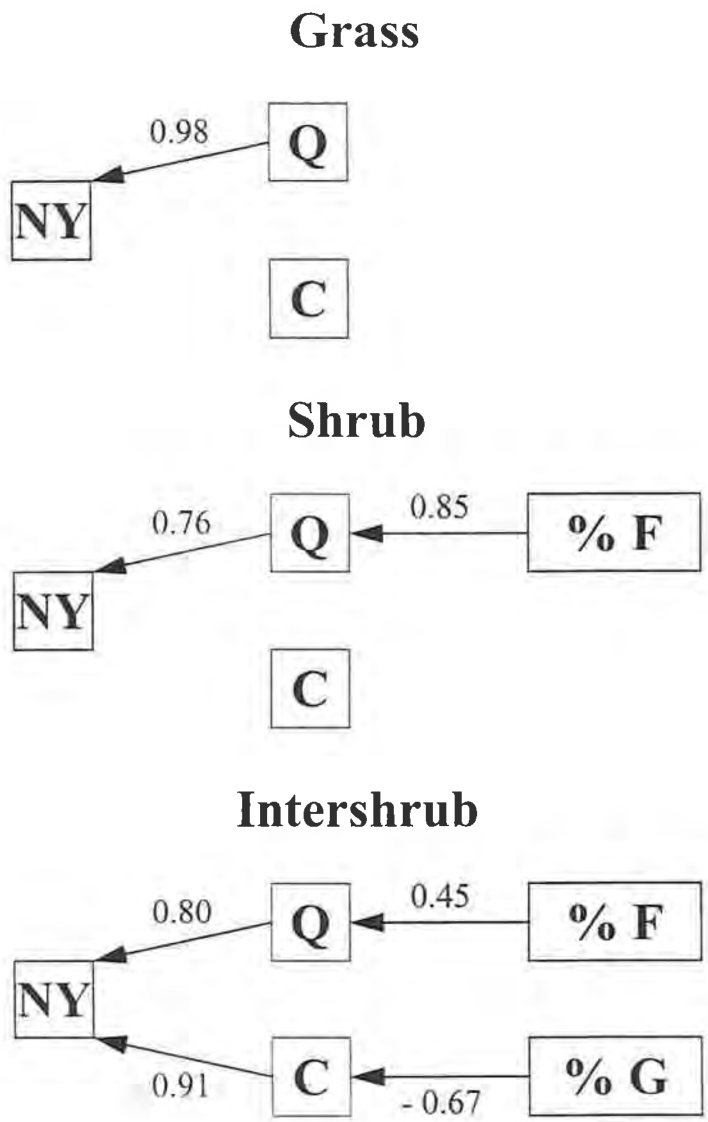


Figure 6. Flow diagrams showing controls of nitrogen yield from grassland, shrub, and intershrub plots

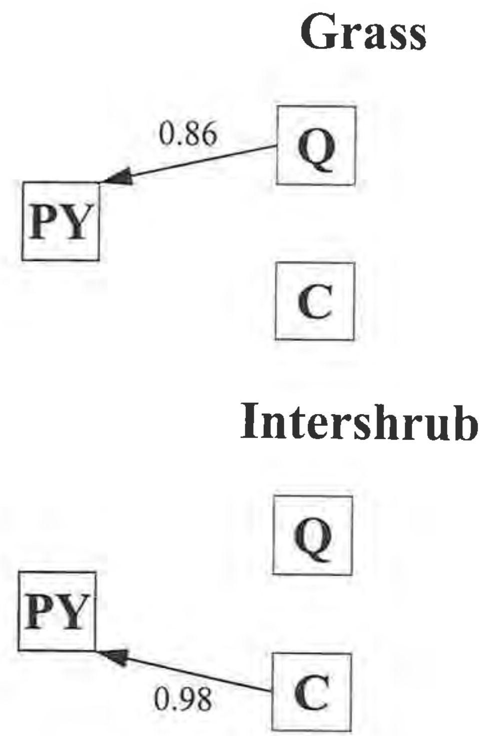


Figure 7. Flow diagrams showing controls of phosphorus yield from grassland and intershrub plots.

Small-Watershed Model

The bajada surfaces at Jornada are characterized by two types of drainage system: in the first type the drainage originates in the mountains behind the bajada, whereas in the second type it originates on the bajada itself. This model is concerned with the second type of drainage system. The ultimate purpose of the model is to predict the horizontal flux of water and nutrients into and out of patchs and through patch mosaics. These predictions may then be used as input into plant growth models such as PALS. The cell size in the present model is therefore in the order of 1 x 1 m, which is the typical size of a shrub.

Model Objectives

1. To *develop* a Runoff and Erosion Simulaor for Arid Lands (RESAL) that will predict the movement during individual rainstorms of water, sediment, and nutrients through two small shrub-covered watersheds.

2. To *parameterize* RESAL by means of detailed mapping of the topography and shrub locations and small-scale rainfall simulation experiments to establish separate infiltration, soil detachment, and nutrient loss equations for shrub and intershrub cells.

3. To *validate* RESAL by comparing predicted and measured hydrographs, sedigraphs, and solutegraphs at flumes installed at the outlets of the two watersheds.

Model Development

RESAL is based on KINEROS2 the latest release of a KINematic runoff and EROSion model originally developed by the USDA Agricultural Research Service. However, RESAL is different is a number of significant ways to KINEROS2 (Figure 8). In particular, RESAL allows for convergent and divergent overland flow, such as occurs around shrubs on actual hillslopes. It also can operate with several thousand cells, whereas KINEROS can accommodate a maximum of 20 overland flow elements. The hydrology component of the model is complete. The sediment and nutrient transport components need additional work.

Parameterization

The rainfall simulation experiments needed to obtain infiltration curves, soil detachment relations, and nutrient uptake relations for shrub and intershub cells within the model are complete.

Validation

Automatic rain gauges, water level recorders, and sediment/solute samplers have been installed at the outlets of two watersheds with areas of 775 and 889 m^2. We expect

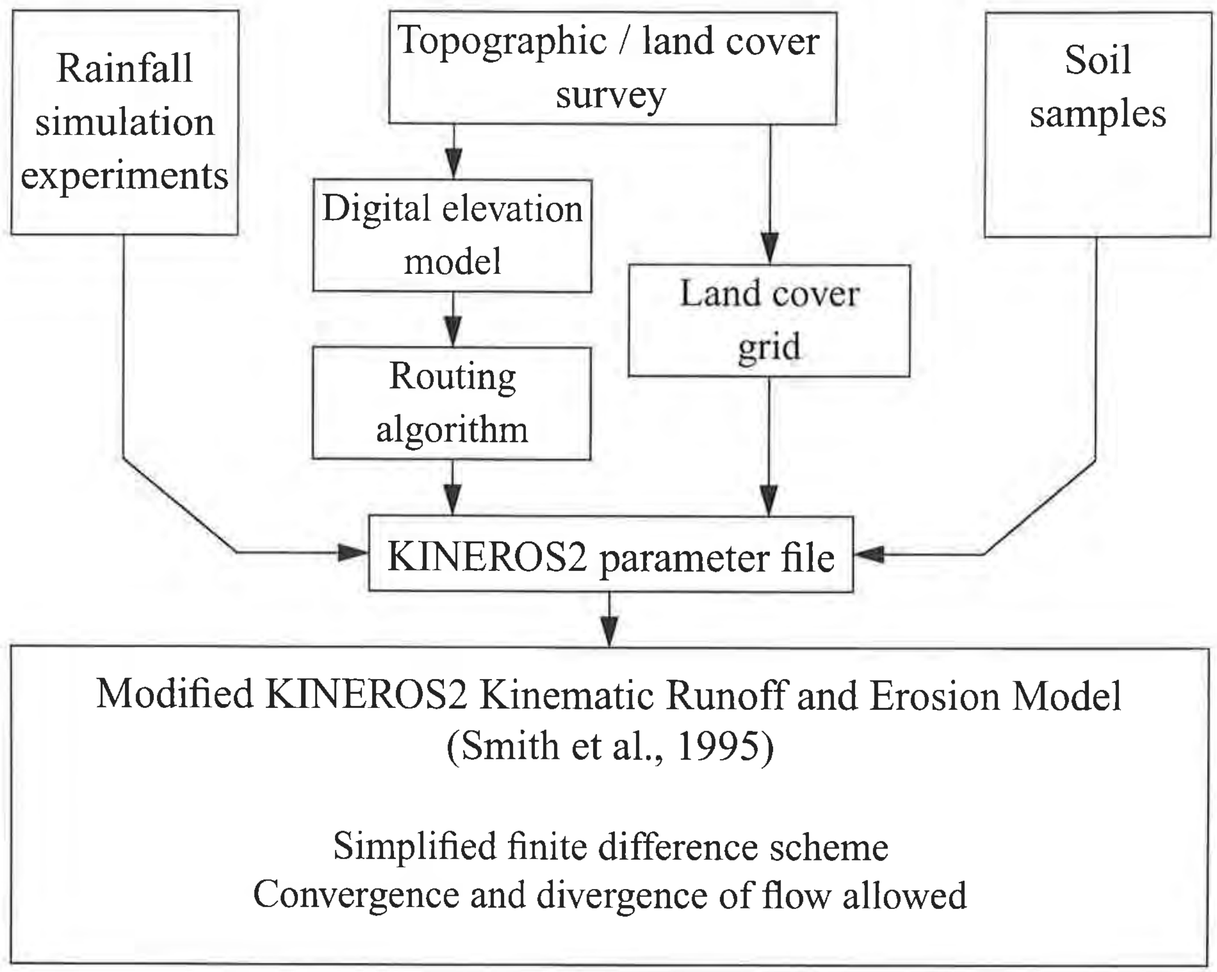


Figure 8. Model configuration.

to be able to validate the model using data collected by these instruments this (1997) summer.

Bajada-Scale Model

Summary of Model

The bajada-scale model allows the routing of water generated by a Horton excess mechanism across the surface of the bajada. The bajada surface is defined by the Digital Elevation Model (DEM) supplied by the USGS. The infiltration model used is the Smith and Parlange (1978) three-parameter model which allows the simulation of runon infiltration. The infiltration model works on a surface layer, with an additional deep drainage term for the deep percolation of water below the root horizon. Infiltration parameters for individual cells will be defined by one of two methods: either by the use of distribution functions obtained from the field experiments or by using Thematic Mapper (TM) data to define surface properties of cells and relating these properties to those of the field experiments. Flow routing is carried out by the solution of the kinematic wave equations using one of two approaches. The first assumes that interrill and rill flow can be treated in the same way at the 30-m cell size. The second routes runoff generated on interrill areas into rills, and from there down the bajada until either the playa is reached or the rill disperses in a bead. Criteria for distinguishing between rills, beads, and interrill cells will be based on topographic parameters calculated from the DEM. Friction factors, both for rill and interrill flow, will be determined from field experiments and assigned according to whatever routing method is used. Rainfall will be distributed according to a number of scenarios (e.g., either uniform distribution or concentrated in storm cells on particular parts of the bajada). This hydrological model will then form the basis of a coupled model to describe sediment and nutrient transfers for unltimate integration with plant growth models.

Progress to Date

1. Field data have been collected to parameterize the following components of the model: infiltration rates (rill and interrill but not beads), friction factors (rill and interrill but not beads) and sediment and nutrient transport (interrill only). Two watersheds have been instrumented to monitor discharge and sediment and solute transport data to validate the model.

2. Model runs have been carried out with uniform parameters and rainfall without definition of rill cells. The runs suggest that flow occurs along distinct channels, and there is some reproduction of increasing and decreasing flow down the bajada, which would be consistent with the formation of beads.

3. Two small-scale models have been implemented to attempt to define the rill-interrill-bead criteria more clearly. The first demonstrates the sensitivity of discharge and hence sediment transport to slope changes, suggesting that slope may be important variable

controlling the transport system. The second looks at the impact of plan curvature on discharge and sediment transport. The code for this model has been written but the model has not yet been run.

4. Mixture modeling of the available TM image has been undertaken to define the surface characteristics. The results show a good correlation for green and dead vegetation, soil, and rock cover.

Disturbance

Disturbance in desert ecosystems can be either chronic or acute in effect, and natural or anthropomorphic in nature. Generally, episodic acute disturbances are characteristic features of arid environment.

Historically, the Chihuahuan desert has supported low, chronic levels of herbivory by native animals. Many general theories describe the role of herbivores in shaping grassland and shrubland ecosystems, but none of these easily accommodates the inclusion of a large, exotic, domesticated ruminant in an arid system. For the past 125 years grazing by livestock has generally functioned as an acute, episodic disturbance in the Chihuahuan desert. Late in the 19th century high stocking rates over a brief period of 10-15 years resulted in significant, pronounced, rapid, and documented vegetation changes.

With various management and economic controls in place during the last half of the 20th century, acute stress from livestock stems from grazing during drought rather than excessively high stocking rates. When cattle remove a large portion of the net primary production during a drought period their grazing is an acute, episodic stress.

The central hypothesis of the Jornada LTER-III suggests that the Chihuahuan desert ecosystem is strongly shaped by structural features, especially the spatial distribution of plant and soil resources. We hypothesize that the severity of an acute disturbance is also shaped by ecosystem structure.

We designed long-term study plots--Stressors I and II--to test this hypothesis. Within a grassland/shrubland ecotone, we have applied livestock grazing (a single 24 h defoliation of the standing crop within a 365 d period) during either winter dormancy or summer growth periods. These grazing treatments are applied in enclosures with or without mesquite. Primary response variables are changes in vegetation composition, cover, and aspects of plant demographics. Changes in the distribution of soil resources are also monitored (see core area 3).

It is important to note that this experiment is not designed to establish chronic, sustainable defoliation rates that reflect grazing capacity. Given the episodic nature of grazing as an acute disturbance in this environment, studies of this nature would be irrelevant and inconclusive.

When mesquite is present, we expect that a canopy cover >8% will lead to a persistent shrub-dominated community irrespective of season of defoliation. In the absence of mesquite, we expect the grassland will persist even with acute disturbance. However, the species composition of the grassland community may shift to include species more resistant to herbivory.

We regard this experiment as important to identifying thresholds in response to grazing, clarifying the role of ecosystem structure in determining vegetation responses to disturbance, and developing guidelines to remediate landscapes that have been altered by grazing during the past 125 years.

Following the 1996 growing season we estimated basal cover and composition by species for all subplot treatments at stressor site I. Subplot effects are artificial seasonal (either July-September or October-June) drought using portable rain out shelters, a single summer season prescribed burn of above-ground biomass, and nutrient depletion of soils achieved by annual summer additions of 1 kg of glucose per plot. These treatments were initially applied in either 1994 (rain out shelter installed) or 1995 (burning and nutrient depletion treatments).

Responses of vegetation classes to acute seasonal defoliation were particularly pronounced (Fig 1a). Perennial grass cover was reduced ($P<.01$) by 54% in response to either season of defoliation. However, basal cover for grazed plots was still between 10 and 11%. Typically, desert grasslands dominated by black grama have between 10-15% basal cover under favorable climatic periods of average or above annual precipitation. Total vegetative cover was similar between nongrazed and winter grazed treatments. The increased response of annuals, both grasses and forbs, under winter grazing offset the cover reductions in perennial grasses compared to nongrazed. The annual grasses under summer grazing did not demonstrate a similar release response, and total vegetative cover under summer grazing was reduced by about 24%.

Basal cover reductions in response to summer drought were extremely dramatic (Fig. 1b), and were more pronounced than for any other treatment, including acute grazing. All nonwoody vegetation classes were significantly reduced by summer drought. Winter drought reduced perennial grass cover, but other classes were comparatively insensitive.

Responses to shrub competition were nonexistent (Fig. 1c), as expected for the early stages of this long-term study. Plots were established based on equivalent cover of perennial grass and an absence of mesquite. Influences of mesquite competition are not expected to be manifested for a number of years.

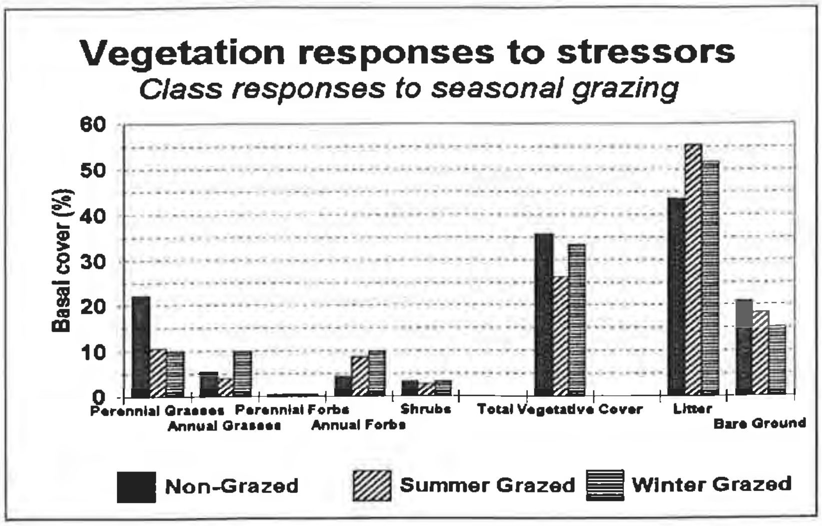
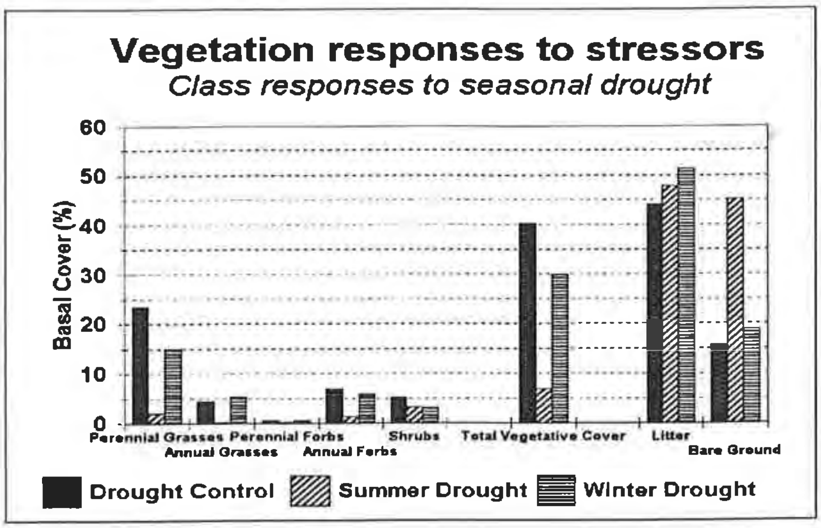
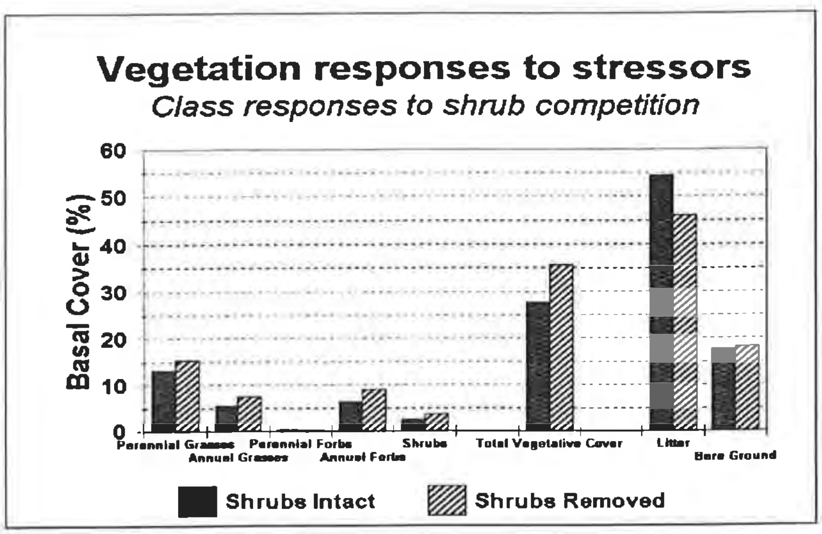


Figure 1. Basal cover of vegetation classes following the 1996 growing season in response to various stressors applied to 4x5 m subplots in a desert grassland.

(A) Acute grazing treatments applied in either August (summer) or February (winter) from 1994-96.



(B) Simulated drought treatments using greenhouse plastic-covered shelters maintained over subplots from either October-June (winter) or July-September (summer).



(C) Shrub competition treatments applied in March, 1994, and subsequently maintained, consisting of either basal severing of mesquite and hand removal or leaving mesquite intact on site.

Patch and landscape models. James F. Reynolds, Duke University

We are developing the Patch Arid Lands Simulator (**PALS**) and the REgional General Arid Lands Simulator (**REGALS**). Our modeling approach is based on the hypothesis that transitions in ecosystem structure and function are best understood in the context of the spatial and temporal distributions of soil resources and the capacity of different plant functional types (PFTs) to respond to these distributions.

PALS. *I. Predicting the role of climate change and disturbance on rates of desertification*. PALS simulates phenology, water and nutrient uptake, and growth of PFTs (shrubs, C_4 grasses, and annuals/herbs) as a function of soil water and nutrients (Fig. 1). Soil water and nutrients are functions of variable inputs (rainfall, litter) as well as plant and microbial processes. Simulations with PALS suggest that changes in rainfall (climate change) and changes in PFT composition (disturbance) affects production, stability, and "success" of PFTs in both direct and indirect ways. We can examined changes in seasonal distribution of rainfall, specific PFT combinations, variability in timing of rainfall, changes in root/shoot allocation, shifts in nitrogen availability, herbivory, and variability in soil types (Fig. 2). We are considering these modeling results in view of divergent hypotheses regarding the causes of desertification.

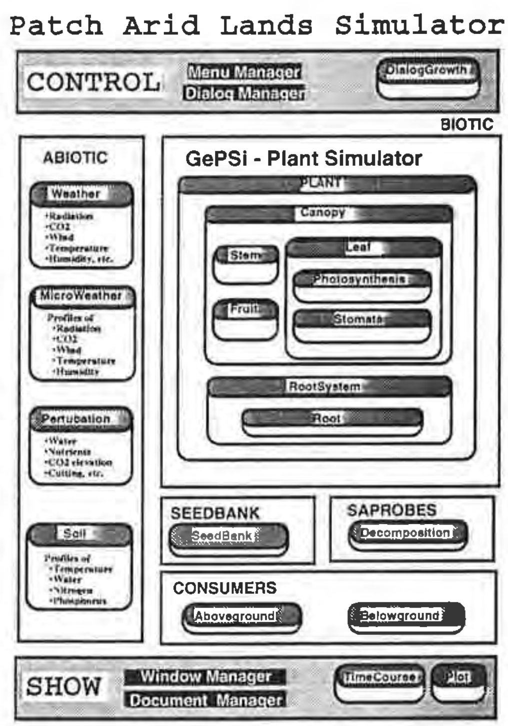


Fig. 1. Overview of PALS ecosystem model in OOPs (object-oriented programming) format. Rectangles represent group of classes provided by the class libraries in the C++ software package (SYMANTEC 6). Round-cornered rectangles represent classes in PALS. Blocks CONTROL and SHOW provide real time input and output interfaces with PALS, allowing parameter values to be changed and model results displayed. Modified from Chen & Reynolds (1997).

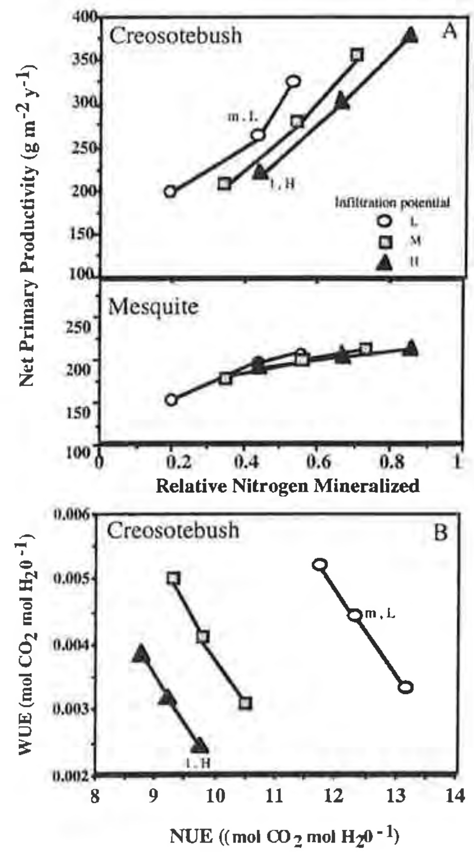


Fig. 2. Output from PALS showing the interactions of N-mineralization and infiltration potentials on NPP in creosotebush and mesquite Patch EFTs. From Reynolds et al. (1997).

PALS. *II. Predicting the effects of drought on above- and belowground litter decomposition and nitrogen cycling*. The stability of shrublands under changing climate will depend on the physiological responses of the shrubs and on plant-soil interactions mediated through litter decomposition and mineralization. In a 4 year field study (Reynolds et al. 1997), we examined decomposition (mass loss) and nutrient content (C/N) of litter from *Prosopis* and *Larrea* shrubs in control plots and in plots where summer rain was excluded using shelters. Overall decomposition rates were significantly lower for creosotebush litter than for mesquite and induced summer drought reduced mass loss for both species. PALS predicted the patterns of mass loss and the main effects of drought on litter dynamics. Our experimental results and simulations indicate that long-term decline in summer rainfall will lower decomposition rates and inhibit mineralization more than nitrification, with important ecosystem implications.

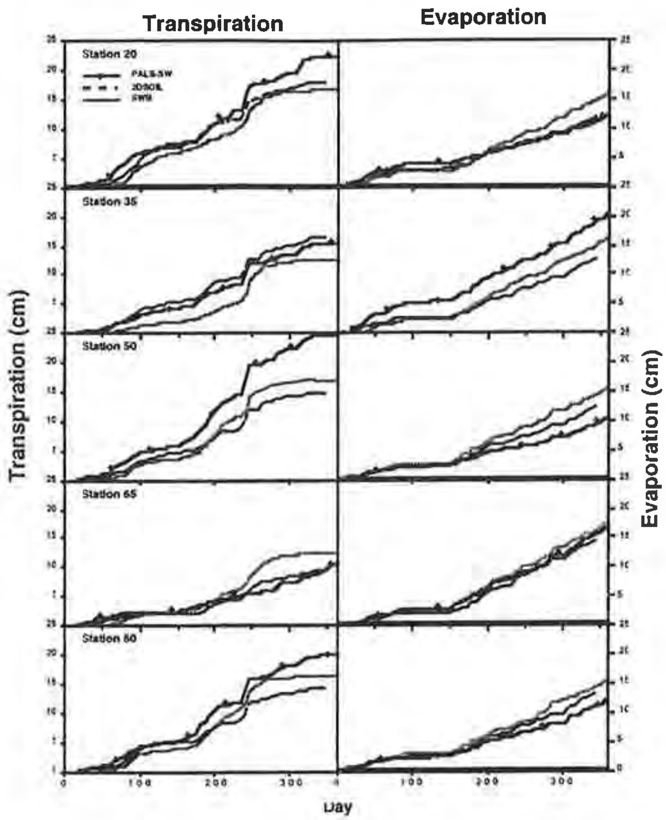


Fig. 3. Predicted amounts of transpiration and soil evaporation along the LTER transect with PALS and 2 other models (SWB and 2DSOIL). With exception of station 35, models predict that stations with high plant cover have high transpiration and low evaporation. Thus, despite some quantitative differences among the models, the ratio of transpiration to total evapotranspiration along the transect was similar. While Station 35 had the highest peak plant cover, it was predicted by PALS–SW and SWB to have low transpiration water loss, relative to other stations and relative to the evaporation loss. Neither evaporation nor transpiration were strongly related to soil texture: PALS–SW predicted similar evaporation and transpiration from stations 20 and 80, which had similar total plant cover, but different soil texture—19 versus 8 percent clay, respectively, and PALS–SW predicted different total transpiration and evaporation for stations 20 and 35, which had similar soil textures, although somewhat different cover. Although we could not validate soil evaporation and transpiration predictions against actual measurements, we can indirectly evaluate the results based on the degree to which the modeled soil water distributions fit the actual soil water patterns over the entire soil profile. A high degree of convergence over the entire profile suggests that the proportions of water extracted from the surface (primarily evaporation) *versus* deeper layers (primarily transpiration) is qualitatively correct. From Kemp et al. (1997)

PALS. *III. Predicting effects of variation in rainfall and disturbance on soil water dynamics in the Chihuahuan Desert.* Understanding the interactions and feedbacks between soil water dynamics and PFGs is critical for predicting the effects of climate change and grazing on rates of desertification. We used PALS to investigate the effects of variation in rainfall on soil water dynamics in different community types in the Jornada Basin. PALS was parameterized with an intensive data set collected from a 2.7 km transect of varying plant life forms and cover. We then predicted soil water dynamics, evaporation, and transpiration over multi-year periods with different variations in rainfall. The results reveal how variation in plant life form and function, cover, and root distribution — all of which are likely to change in response to disturbance — interact with rainfall regimes and soil type to produce very different patterns of soil water storage and loss rates. Our results help explain highly divergent conclusions that have been proposed regarding evapotranspiration in arid shrubland communities (Fig. 3).

REGALS. *I. A simple landscape model of plant population dynamics that extends the concept of area of influence by considering "compensatory" growth of root systems.* This model (Brisson & Reynolds 1997) is motivated by our recent field study of *Larrea* at the Jornada LTER site, where we found that asymmetry in the horizontal extent of root systems was related to competitive pressure of neighbors (Brisson & Reynolds 1994). The ability of a plant to grow roots into soil zones free of neighbors in response to competitive pressures is expressed by a single parameter in the CPM (Compensatory Population Model). Our *Larrea* population nicely fits the 2-dimensional structure of the pixel-based CPM since lateral roots are extensive, but occur within a narrow range of depth, and overlap between neighboring root systems is minimal. Our results (Fig. 4) suggest that morphological plasticity in growth of individuals can reduce the possibility that a population exhibits a regular distribution. In our simulations, there is no heterogeneity, the population is even-aged, and mortality is due entirely to competition, yet a regular distribution of shrubs is delayed when plants exhibit compensatory growth. Lack of observed regularity in the field may therefore be partially attributed to the biology of the species. Despite its simplicity, our CPM of competition for space can mimic fundamental elements of population dynamics commonly observed, including a decrease in population size with time due to competition, self-thinning, and the change from clumped to regular spatial distribution resulting from density-dependent mortality. These results will be useful in our extended models based on cellular automota (see below).

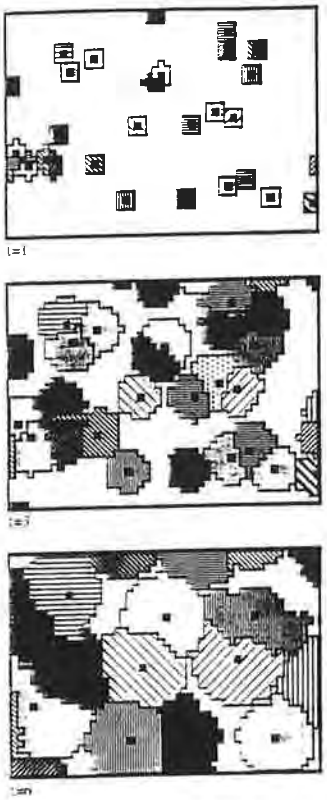
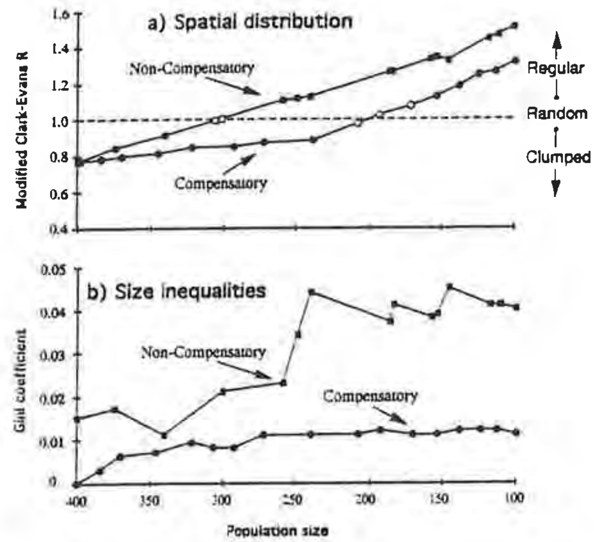


Fig. 4. LEFT: Changes in spatial distribution of roots at years 1, 3, 6 for plants with compensatory growth ((i.e. show plasticity by expanding into regions free of neighbors). BELOW: Change in spatial distribution and size inequalities as a function of population size for plants with and without compensatory growth. Geni coefficient = 0 (if all individuals have equal size; =1 when all but 1 individual of an infinite population has a size of 0). From Brisson & Reynolds (1997).



CAM: Cellular Automaton-Markov model

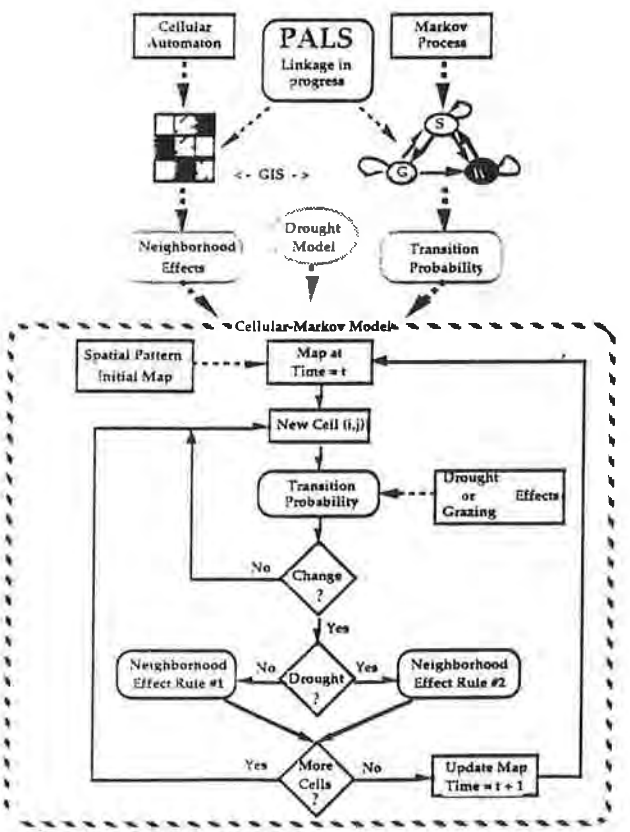
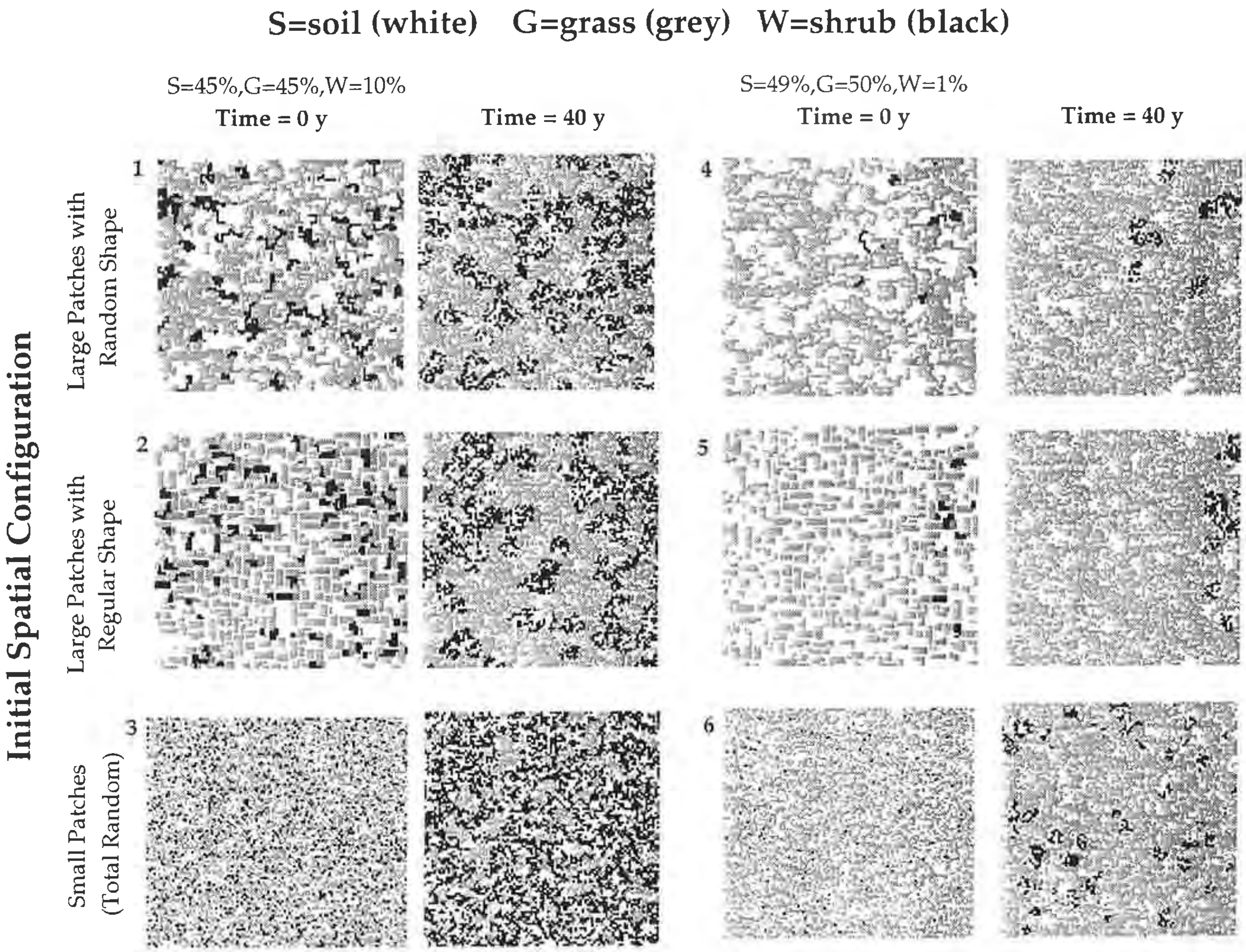


Fig. 5. Flow chart for CAM.1.

REGALS. *II. Combined principles of Cellular Automata with Markov transition probabilities with neighborhood (spatial) effects.* This version of REGALS is called CAM.1 (see Fig. 5). CAM.1 uses 3 functional groups (i.e., cover types of soil, grass, woody shrub). In our preliminary runs, we used a regular lattice of 50x50 cells, each of which is occupied by one of the cover types. Drought is defined by a time series generated as a random event with two parameters: frequency (uniform distribution) and length (geometric distribution) of droughts. Grazing affects transition probabilities. The neighborhood effect is a function of the state of a cell and the number of neighbors of different functional types. We experimented with three factors to determine their relative importance in vegetation dynamics and ran the model with initial maps of different spatial configurations with transition probabilities that were a function of disturbances (i.e., climate and grazing) and neighborhood configurations, and examined trends of landscape indices over time. This allows us to establish relationships between the probability of landscape change and the relative importance of the four factors. Some preliminary results are shown in Fig. 6. Eventually, PALS will be used to estimate the transition probabilties (see Fig. 5).

Fig. 6. CAM.1 output, showing initial configuations of patch mosaics and after 40 years (low drought frequency and no grazing). From Li & Reynolds (1997).



Literature cited

Brisson, J. & Reynolds, J.F. (1994) The effect of neighbors on root distribution in a creosotebush (*Larrea tridentata*) population. *Ecology* **75**, 1693-1702.

Brisson, J. & Reynolds, J.F. (1997) Effects of compensatory growth on population processes: A simulation study. *Ecology* **In Press.**

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Kemp, P.R., Reynolds, J.F., Pachepsky, Y. & Chen, J.L. (1997) A comparative modeling study of soil water dynamics in a desert ecosystem. *Water Resour Res* **33**, 73-90.

Li, H. & Reynolds, J.F. (1997) Modeling effects of spatial pattern, drought, and grazing on rates of rangeland degradation: A combined Markov and cellular automaton approach. *Scaling of Remote Sensing Data for Geographical Information Systems.* (eds D.A. Quattrochi & M. Goodchild), pp. 211-230. Lewis Publishers, Chelsea, Mi.

Reynolds, J.F., Virginia, R.A. & Schlesinger, W.H. (1997) Defining functional types for models of desertification. *Plant Functional Types: Their Relevance to Ecosystem Properties and Global Change.* (eds T.M. Smith, H.H. Shugart & F.I. Woodward), pp. 194-214. Cambridge Univ. Press, Cambridge, England.

Reynolds, J.F., Virginia, R.A., Kemp, P.R., DeSoyza, A.G. & Tremmel, D.C. (1997) Impact of simulated drought on resource islands of shrubs in the Chihuahuan Desert: Effects of species, season, and degree of island development. *Ecology* **In Review.**

Leadership, Management, and Organization.

The Jornada LTER has undergone a complete transition of scientific management since 1981[1], yet its program of long-term ecological research has continued unabated. Through an active program of networking, we are able to maintain a research program in which a large proportion of the investigators are "non-resident." We make daily use of electronic mail (Internet and LTERnet), monthly use of conference telephone calls, and meetings at the site to maintain all levels of communication. Local scientists at New Mexico State University meet monthly for an informal research seminar, and our annual "Friends of the Jornada" symposium (see page 10-11 under tab, "Scientific Presentations") is an important forum for the exchange of ideas and for the development of group unity among graduate students, technicians, and principal scientists in the pursuit of a common goal.

Management of LTER-III is shown in the organizational chart on the next page. Decisions regarding the conduct of science are made at group meetings of the principal investigators, with consultation of the site manager, John Anderson, regarding potential site conflicts. Decisions regarding the reallocation of financial resources are made by the Executive Committee.

Daily operation of the site at New Mexico State University is coordinated by John Anderson, who reports to Dr. Peter Herman. John Anderson and Kris Havstad approve the location of field projects, arrange field logistics and resolve potential site conflicts. John Anderson maintains daily budgetary oversight at NMSU, with Dr. Vince Gutschick holding the official NMSU faculty signatory power. Dr. Laura Huenneke represents the site in collaboration with the Sevilleta LTER and with our international cooperations at Mapimi and elsewhere.

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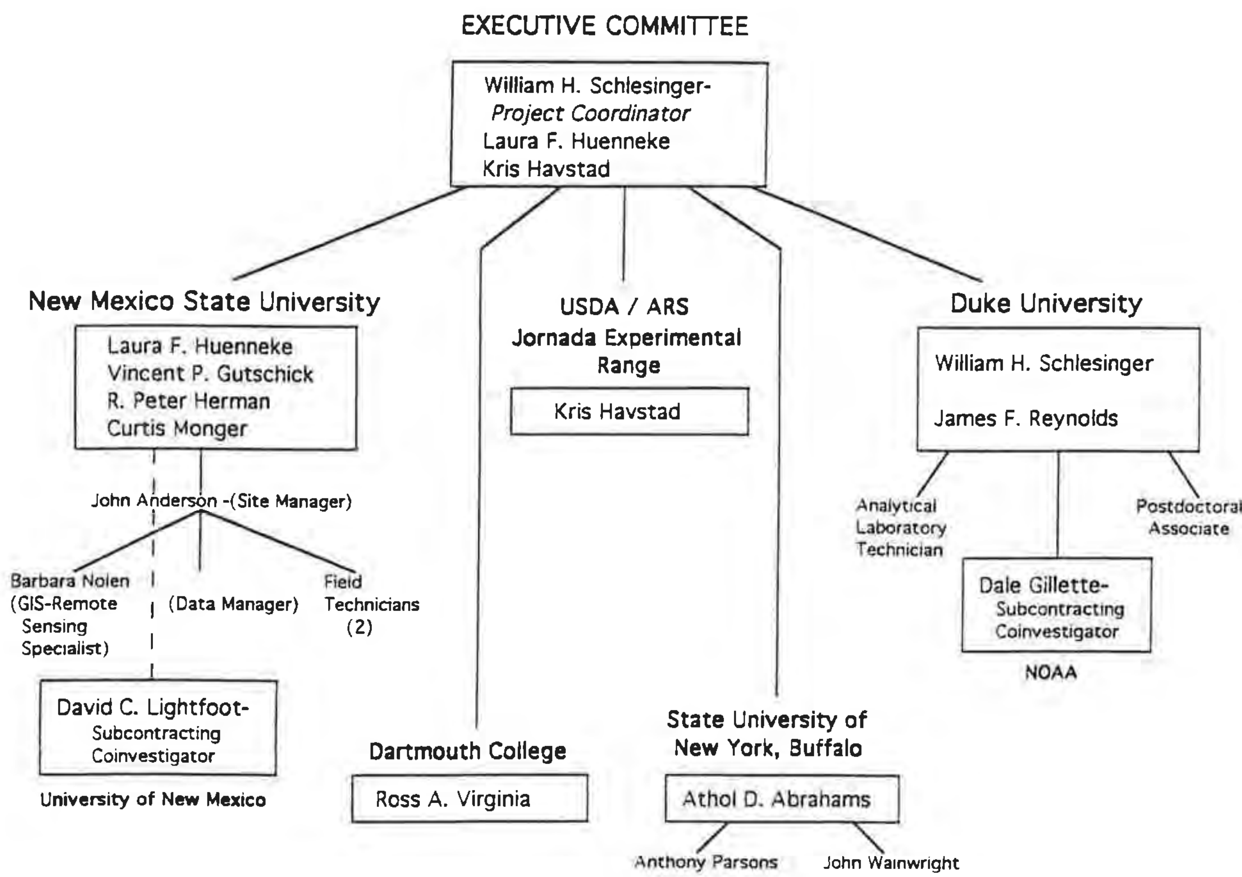
[1] The initial LTER effort (1981-1986), which we call LTER-I, was funded to New Mexico State University with Drs. Whitford, Cunningham, Ludwig, Wierenga, and Conley as co-principal investigators. Their goal was to understand variations in the spatial pattern of vegetation in the Chihuahuan desert, and they established a long-term experiment in which a major resource, soil nitrogen, was augmented across a gradient of vegetation types to examine the convergence of ecosystem function under conditions of resource abundance. Interim funding (1986-1988) allowed a reconfiguration of the Jornada LTER team, which submitted the proposal for LTER-II with funding beginning in January 1989. As a result of retirements (Whitford and Conley) and resignations in favor of other employment (Cunningham, Ludwig and Wierenga), none of the original LTER-I investigators remains with the project. When Dr. Whitford retired in 1991, funding for LTER-II was transferred to Duke University, under the direction of Drs. Schlesinger and Reynolds. They also led the development and submission of the proposal for the current, LTER-III funding (1994-2000).


EXECUTIVE COMMITTEE
William H. Schlesinger-
Project Coordinator
Laura F. Huenneke
Kris Havstad
New Mexico State University
Laura F. Huenneke
Vincent P. Gutschick
R. Peter Herman
Curtis Monger
John Anderson -(Site Manager)
Barbara Nolen
(GIS-Remote
Sensing
Specialist)
(Data Manager)
Field
Technicians
(2)
David C. Lightfoot-
Subcontracting
Coinvestigator
University of New Mexico
USDA / ARS
Jornada Experimental
Range
Kris Havstad
Dartmouth College
Ross A. Virginia
State University of
New York, Buffalo
Athol D. Abrahams
Anthony Parsons
John Wainwright
Duke University
William H. Schlesinger
James F. Reynolds
Analytical
Laboratory
Technician
Postdoctoral
Associate
Dale Gillette-
Subcontracting
Coinvestigator
NOAA

Data management for the Jornada LTER project provides the protocol and services for data collection, verification, organization, long-term storage, and distribution.

Data managers interact with researchers during the entire scientific process--from the initial planning of sampling designs and field data collection to the archiving and distribution of long-term data. Whenever a new LTER project begins, the responsible investigator must file a Research Project Abstract Form (page 3, this section) with the Site and Data Managers.

From that point forward, the data management team helps to build and maintain a database that will be fully documented, error free, and organized in useful ways. Our protocol for data collection and processing seeks maximum interaction between researchers and data management personnel to avoid confusion and potential loss of data.

The data manager helps researchers to construct field and laboratory data sheets that allow convenient data entry and analysis. Data documentation forms (page 4, this section) are completed by principal investigators prior to data entry. These forms contain "metadata" that is later available whenever a particular dataset is requested or obtained via our Web Site. Data are entered into computer data files by data entry personnel using programs that error-check and verify the data as it is entered. Computer files are subjected to further verification by graphing and/or error-checking programs, and/or examination by field investigators. Of course, the final responsibility for quality assurance rests with the investigator who submits data for inclusion in the Jornada LTER Data Management System.

Error-checked data files are stored with associated documentation files on floppy disks and on a hard-disk database. Back-up data files are maintained as "hard-copy," on multiple floppy disks, and on read/write 30-yr magneto-optical disks. Various sets of these data are stored at different sites on the NMSU campus. Data files are readily transferred through the local campus-wide network and the Internet using an ethernet connection and communications software.

The Catalog of Jornada Datasets is accessible through the Jornada Home page on the World Wide Web (page 5, this section). Each listed project has a "hot-link" to the Research Project Description form. The entire Catalog and an example of a Research Project Documentation Form (for a project on soil ammonia volatilization) are included on pages 6-17 of this section. Spatial data and an archive of images are maintained separately (pages 18-19, this section).

In addition to on-line availability of our LTER data, we attempt to satisfy dataset requests that are received by the Jornada LTER office. To these, we respond by email (with attached ftp data files) or by mailing a diskette and/or hardcopy, as appropriate. We are proud of the short turnaround time that we achieve in response to such requests, which is shown on the Jornada LTER Data Request Log included herewith, on pages 20-22 for numerical data and pages 23-26 for spatial data.

We conduct our data management procedures in accord with recommendations and guidelines developed and adopted by the LTER Data Managers group. Meteorological data are available immediately and without authorization. For a 2-year period, access to data from other projects is restricted to the Principal Investigator responsible for the project. When data is used by others, we provide a standard, recommended form of acknowledgement to the Jornada LTER program and the individual investigator responsible.

Jornada LTER **New Mexico State University Research Project Description Form**	Project ID

All Jornada Desert Site NSF/LTER project must be documented on the following form. In addition, associated data sets must also be described on Data Set Documentation forms, available from the Data Manager.

1. Responsible investigator:	**2. PI funding the research:**	**3. Todays date (mm/dd/yy):**

4. Additional investigator(s):

5. Funding agency (ex. NSF):	**6. Funding cycle (ex. LTER III):**

7. Suggested project title: *Give a brief descriptive title for the project.*

8. Date research commenced (mm/dd/yy):	**9. Date research terminated (mm/dd/yy):**

10. Informative abstract: *Describe research project completely. Include objectives, general methods, site locations, and dates. If you need more room attach additional sheet(s).*

Jornada LTER **New Mexico State University Data Set Documentation Form**	Data Set ID

All Jornada Desert Site NSF / LTER data sets must be documented on the following form. This applies to any data set intended for permanent archiving. All raw data set collected under the auspices of the Jornada NFS/LTER Program will be described by the following standardized form. Information that is not available at this time , must be included when available. See data manager for any questions regarding this form.

1. Responsible investigator(s):

2. Todays date (mm/dd/yy):

3. Researchers: *List all personnel who will be obtaining data and who would need to be contacted directly if there is a problem in the raw data.*

4. Project title: *The name of the project that this data set is associated with.*

5. Data set title: *Give a brief descriptive title for the data set.*

6. Suggested file I.D.: *(Max of 8 Characters)*

7. Expected duration of study:	**8. Date data collection commenced:** **mm/dd/yy**	**9. Date data collection terminated** **mm/dd/yy**

10. Frequency of measurement:

11. Methods of recording: *(field data sheets, instrumental. etc.)*

12. Site Location: *Describe in sufficient detail that the site can be re-located. Attach maps if neccessary.*

13. Objectives: *State the hypothesis and/or objectives which collection of data set addresses. Attach additional sheets if necessary.*

Jornada LTER Information:

- Overview
- Jornada Trails newsletter
- Jornada Bibliography
- Data Information:
  - Data Management Policy
  - Data Catalog
  - Data
- Proposals and Reports
- Personnel
- GIS Archive
- Image Archive
- Intersite/Agency

Information Via LTERnet:

- About the LTER program
- LTER Personnel
- All Site LTER Bibliography

JORNADA
LONG-TERM ECOLOGICAL RESEARCH

http://jornada.nmsu.edu

JORNADA DATA CATALOG

Last update: 04/15/1997

Jornada Data Management Policy **LTER Personnel Directory**

Research Categories

- **Animal** Project Documentation Data set documentation
- **Climate** Project Documentation Data set documentation
- **Decomposition** Project Documentation Data set documentation
- **Hydrology** Project Documentation Data set documentation
- **Intersite** Project Documentation Data set documentation
- **Plant** Project Documentation Data set documentation
- **Soil** Project Documentation Data set documentation

Return to Research Categories

Animal Project Documentation

Animal Transects
Abstract: Population densities of rabbits and bird census in various habitats over a series of years.

Arthropod Pitfall Traps-II
Abstract: Pitfall trapping of ground-dwelling arthropods looking at diversity and density during LTER-II.

Arthropod Pitfall Traps-III
Abstract: Pitfall trapping of ground-dwelling arthropods looking at diversity and density during LTER-III.

Lizard Pitfall Traps
Abstract: Pitfall trapping of lizards looking at diversity and density.

Small Mammal Trapping (LTER-II)
Abstract: Small mammal trapping looking at diversity and density.

Small Mammal Exclosure Study
Abstract: The purpose of this study is to determine whether or not the activities of small mammals regulate plant community structure, plant species diversity, and spatial vegetation patterns in Chihuahuan Desert shrublands and grasslands. Ants, termites, and grasshoppers will be monitored since

grasslands. Ants, termites, and grasshoppers will be monitored since manipulations of small mammals will probably affect these arthropod consumers.
INTERSITE study: Jornada LTER; Sevilleta LTER; Mapimi, Mexico

Termite Baits
Abstract: Surface measurement of termite consumption of organic material using baits.

Return to Research Categories

Climate Project Documentation

Climatalogical data (LTER)
Abstract: Climatalogical data from Jornada LTER Weather Station

Evaporation Pan data
Abstract: Weekly pan evaporation at LTER Weather Station.

Precipitation: Monthly accumulation at 15 NPP sites
Abstract: Precipitation: Monthly accumulation at 15 NPP sites using graduated rain gauges (LTER-II)

Return to Research Categories

Decomposition Project Documentation

LTER Fine Litter Decomposition Experiment (LIDET)
Abstract: The primary objective of this study is to examine the control that substrate quality and climate have on patterns of long-term decomposition and nitrogen accumulation in above- and below-ground fine litter.
INTERSITE study: Includes all major terrestrial biomes in North America. Twenty-eight sites are involved.

Termite Baits
Abstract: Surface measurement of termite consumption of organic material using baits.

Return to Research Categories

Hydrology Project Documentation

Groundwater recharge in the Jornada
Abstract: Determination of amount of water recharge under natural conditions using the simulation program SWACROP.

Return to Research Categories

Intersite Project Documentation

LTER Fine Litter Decomposition Experiment (LIDET)

LTER Fine Litter Decomposition Experiment (LIDET)
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INTERSITE study: Jornada LTER; Sevilleta LTER; Mapimi, Mexico

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Return to Research Categories

Plant Project Documentation

Patterns of Net Primary Productivity
Abstract: Patterns of net primary production over a range of ecosystem types and geographic areas of the Jornada basin with biomass and productivity estimates.

Return to Research Categories

Soil Project Documentation

Ammonia Volatilization
Abstract: Ammonia volatilization was measured at three sites. NH3 volatilization is controlled by the rate of mineralization of NH4+ from soil organic matter, and mineralization is stimulated by rainfall.

NPP Soil Water Content
Abstract: Monthly soil water content measurements are made at 10 depths (where possible) at each of 10 access tubes at each of the 15 LTER-II NPP sites using a neutron probe (Campbell Model 503DR Hydroprobe).

Soil-Geomorphic-Vegetation Relationships in the Jornada Basin
Abstract: The goal of this project is to investigate the relationships between soils, geomorphology, and vegetation change in the Jornada Basin. This endeavor is divided into three approaches: (1) field mapping, (2) thin sections of root-fungal-mineral configurations, and (3) prehistoric ecogeomorphic evolution.

Soil Nutrient Distribution In Long-Term NPP Plots
Abstract: Soil nutrient distribution beneath and between plant canopies in mesquite, grassland, playa, creosotebush, and tarbush plant communities in June 1989.

NPP Soil Water Content
Abstract: Monthly soil water content measurements are made at 10 depths (where possible) at each of 10 access tubes at each of the 15 LTER-II NPP sites using a neutron probe (Campbell Model 503DR Hydroprobe).

Transect Soil Water Content

Abstract: Soil water content measurements at 5 depths at 30 meter intervals on 2 LTER-I transects extending along a 2.7 km elevational gradient where one transect was treated with nitrogen once annually from 1982 - 1987. Measurements taken at 2 week intervals from April 1982 to 1987, monthly since.

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- **Animal Transects**
  Abstract: Population densities of rabbits and bird census in various habitats over a series of years.
- **Arthropod Pitfall Traps-II**
  Abstract: Pitfall trapping of ground-dwelling arthropods looking at diversity and density during LTER-II.
- **Arthropod Pitfall Traps-III**
  Abstract: Pitfall trapping of ground-dwelling arthropods looking at diversity and density during LTER-III.
- **Groundwater recharge in the Jornada**
  Abstract: Determination of amount of water recharge under natural conditions using the simulation program SWACROP.
- **Lizard Pitfall Traps**
  Abstract: Pitfall trapping of lizards looking at diversity and density.
- **Ammonia Volatilization**
  Abstract: Ammonia volatilization was measured at three sites. NH3 volatilization is controlled by the rate of mineralization of NH4+ from soil organic matter, and mineralization is stimulated by rainfall.
- **Plant Nutrient Distribution In Long-Term NPP Plots**
  Abstract: Plant tissue chemical analyses for selected species.
- **Soil Nutrient Distribution In Long-Term NPP Plots**
  Abstract: Soil nutrient distribution beneath and between plant canopies in mesquite, grassland, playa, creosotebush, and tarbush plant communities in June 1989.
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Abstract: The primary objective of this study is to examine the control that substrate quality and climate have on patterns of long-term decomposition and nitrogen accumulation in above- and below-ground fine litter.
INTERSITE study: Includes all major terrestrial biomes in North America. Twenty-eight sites are involved.

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Return to Research Categories

Animal Data Set Documentation

Animal transect
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: birds, rabbits, lizards, animals, consumers, populations
Abstract: Population densities of rabbits and bird census in various habitats over a series of years.

Arthropod pitfall trap data (LTER-II)
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: arthropods, pitfall traps, consumers, populations
Abstract: Data for arthropods captured in pitfall traps on LTER II consumer plots. Data includes order, family, genus, species, and number.

Arthropod pitfall trap-III
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: lizards, pitfall traps, animals, consumers, populations
Abstract: Data for arthropods captured in pitfall traps on LTER III consumer plots. Data includes order, family, genus, species, and number.

Lizard pitfall trap data
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: arthropods, pitfall traps, consumers, populations
Abstract: In conjunction with net primary production studies, consumer and faunal studies are conducted at or near NPP sites using pitfall traps. We use live traps, not employing ethylene glycol or other killing/preservative agents, with traps checked once a week at the minimum. Sampling-with-replacement is used with the lizards. Variables measured include species, sex, recapture status, snout-vent length, total length, weight, and whether tail is broken or whole.

Small mammal trapping (LTER-II)
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: small mammals, animals, consumers, populations
Abstract: Small mammal live-traps are located on consumer pitfall plots. A grid of 20 traps is located on each consumer plot. Small mammals are trapped daily for a one-week period in the late spring and again in the late summer of each year. Data on species, sex, toe marks, weight, and reproductive condition are taken.

SMES rodent trapping data

Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: rodents, rodent trapping, small mammals, soil disturbance
Abstract: Rodent trapping webs are being used to determine the composition of rodent species at each study site, and to estimate densities of each species over time.

SMES vegetation line intercept data
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: vegetation, plant species, line intercept
Abstract: Plant line intercept measurements are made along 6 lines within each of the 36 plots. Intercept length of plant species and bare soil are recorded.

SMES vegetation quadrat data
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: vegetation, plant species, canopy cover
Abstract: Plant species composition, cover, and above ground foliage height will be measured from each of the 36 quadrats on each plot.

Termite bait data
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: termites, consumers, foraging activity
Abstract: Data for Jornada LTERII termite bait weight loss. Toilet paper roll termite baits are placed on grids on each consumer plot. Data include initial bait weights and bait weights after baits have been retrieved from the field once each year. Weight loss is calculated as a measure of termite foraging activity.

Return to Research Categories

Climate Data Set Documentation

Climatalogical data (Jornada LTER Weather Station)
Data set access: UNRESTRICTED Requires notification of Jornada LTER Data Manager prior to downloading.
Keywords: air temperature, relative humidity, precipitation, wind speed, wind direction, solar radiation, soil temperature, climate, weather
Abstract: Hourly and Daily Summary climate data is collected for Wind Speed, Wind Direction, Solar Radiation, Relative Humidity, Precipitation, Air Temperature, and Soil Temperature.

History Log **Data: Daily Hourly**

Evaporation pan data (Jornada LTER)
Data set access: UNRESTRICTED Requires notification of Jornada LTER Data Manager prior to downloading.
Keywords: evaporation, water temperature, precipitation
Abstract: Surface evaporation is measured weekly using an evaporation pan compatible with standard National Weather Service evaporation measurements. The following data is collected approximately once a week: max, min, and current H2O temperatures; initial water level; final water level; rainfall.
DATA (46 kb)

Precipitation: Monthly accumulation at 15 NPP sites (LTER-II)
Data set access: UNRESTRICTED Requires notification of Jornada LTER Data Manager prior to downloading.
Keywords: precipitation, rainfall
Abstract: Collection is made of total monthly precipitation at the 15 Net Primary Production sites on the day that monthly soil water content measurements are made in order to correlate precipitation input with belowground water content both spatially and temporally.
DATA (79 kb) **History Log**

Return to Research Categories

Decomposition Data Set Documentation

Termite bait data
Data set access: RESTRICTED Requires release authorization by responsible investigator.
Keywords: termites, consumers, foraging activity
Abstract: Data for Jornada LTERII termite bait weight loss. Toilet paper roll termite baits are placed on grids on each consumer plot. Data include initial bait weights and bait weights after baits have been retrieved from the field once each year. Weight loss is calculated as a measure of termite foraging activity.

Return to Research Categories

Hydrology Data Set Documentation

Return to Research Categories

Intersite Data Set Documentation

LTER Fine Litter Decomposition Experiment (LIDET)
Data set access: RESTRICTED Requires release authorization by responsible investigator.
Keywords: decomposition, decay rates, litterbags, leaf litter, fine roots, wood, nitrogen, phosphorus, carbon fractions.
Abstract: The primary objective of this study is to examine the control that substrate quality and climate have on patterns of long-term decomposition and nitrogen accumulation in above- and below-ground fine litter.
INTERSITE study: Includes all major terrestrial biomes in North America. Twenty-eight sites are involved.

Return to Research Categories

Plant Data Set Documentation

Net primary production quadrat data
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: productivity, harvest, plants, spatial and temporal patterns
Abstract: Standing biomass is sampled three times a year: in winter (February - March), before shrubs begin spring growth; in spring (May), when shrubs and spring annuals have reached peak biomass; in fall (late summer; October), when summer annuals have reached peak biomass but before killing frosts. Data collected include percent cover, height, and phenological stage.

Net primary production reference harvest data
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: vegetation, plant species, canopy cover
Abstract: This is the reference harvest biomass data of plants near, but outside the grid of permanent NPP quadrats that was harvested for each of 15 sites located in 5 plant community zones. Height and cover are recorded in the field. Live biomass is weighed in the lab and all measurements are recorded as reference harvest data.

Plant nutrient distribution beneath and between plant canopies in the mesquite, grassland, playa, creosotebush, and tarbush plant communities
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: plant nutrients, mesquite, grassland, playa, creosotebush, tarbush
Abstract: The LTER plant biomass plots were harvested during spring, fall, 1989 and winter 1990, in 5 vegetation zones (Mesquite, Grassland, Playa, Creosotebush, Tarbush), 3 sites per zone (site with low, medium, and high biomass, ranked based on fall-89 biomass). Samples were analyzed for total Kjeldahl N, and total phosphorus.

Return to Research Categories

Soil Data Set Documentation

Nitrogen volatilized as ammonia -- 1988
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: ammonia volatilization, trace gas fluxes
Abstract: Ammonia volatilization was measured at creosotebush, grassland, and playa sites in the Chihuahuan Desert.
DATA (18 kb)

Nitrogen volatilized as ammonia -- 1989
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: ammonia volatilization, trace gas fluxes, ammonium, nitrate
Abstract: Ammonia volatilization was measured at creosotebush, grassland, and playa sites in the Chihuahuan Desert.
DATA (4 kb)

NPP soil water content
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: soil water content

Abstract: Monthly soil water content measurements made at 10 depths (where possible) at each of 10 access tubes at each of the 15 LTER-II sites using a neutron probe (Campbell Model 503DR Hydroprobe).

NPP soil water content raw data
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: soil water content
Abstract: Raw count data from monthly soil water content measurements made at 10 depths (where possible) at each of 10 access tubes at each of the 15 LTER-II sites using a neutron probe (Campbell Model 503DR Hydroprobe).

Soil nutrient distribution in long-term NPP plots
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: soil nutrients, mesquite, grassland, playa, creosotebush, tarbush
Abstract: The LTER plant biomass plots was sampled in June 1989. A total of 750 soil samples were collected from 5 depths (0- 10, 10-20, 20-40, 40-60, 60-100 cm), 2 locations (under and between shrubs), within 5 vegetation zones (Mesquite, Grassland, Playa, Creosotebush, Tarbush), 3 sites per zone (site with low, medium, and high biomass, ranked based on FALL-89 biomass), and 5 directions per site (in buffer zone just outside of NPP plots N, S, E, W, and in the center of NPP plots C). Samples were analyzed for pH, $CaCO_3$, $NaHCO_3$-extractable P, KCl-extractable NH_4 and NO_3, total kjeldahl N, Saturation extrac cations, and DTPA-extractable micronutrients.

Transect soil water content
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: soil water content, transect, lysimeter, spatial variability
Abstract: Monthly soil water content measurements made at 5 depths at each of 89 stations on the LTER-I Control transect and at every 5th station on the nitrogen fertilized LTER-I Treatment transect using a neutron probe (Campbell Model 503DR Hydroprobe).
DATA (by year) **History Log**

Transect soil water content raw data
Data set access: RESTRICTED Requires release authorization by responsible investigator .
Keywords: soil water content, transect, lysimeter, spatial variability
Abstract: Raw count data from monthly soil water content measurements made at 5 depths at each of 89 stations on the LTER-I Control transect and at every 5th station on the nitrogen fertilized LTER-I Treatment transect using a neutron probe (Campbell Model 503DR Hydroprobe).

Return to Research Categories

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== **Data Set Documentation**

CLIMATE

- NPP Precipitation (Graduated Rain Gauge)

PLANTS

- Net Primary Production - Plant Dimensions
- Net Primary Production - Reference Harvest

SOIL

- NPP Plot Soil Chemistry
- Transect Soil Water Content

JORNADA LTER
New Mexico State University
Research Project Description Form

All Jornada Desert Site NSF / LTER projects must be documented on the following form. In addition, associated data sets must also be described on Data Set Documentation Forms, available from the data manager.

---

1) Project title:

Ammonia volatilization

2) Responsible investigator:

William H. Schlesinger

3) Date research commenced (mm/dd/yyyy):

06/08/1988

4) Date research terminated (mm/dd/yyyy):

June 1989

5) PI funding the research:

W. H. Schlesinger

6) Additional investigator(s):

William T. Peterjohn

7) Funding agency (ex. NSF, USDA):

NSF/LTER

8) Funding cycle (Ex. LTER II, N/A):

LTER II

9) Informative abstract (Describe research project completely. Include project OBJECTIVES/HYPOTHESIS.)

Little is known about the loss of NH3 from non-agricultural soils. Many native soils in arid regions have alkaline pH and may be a significant source of NH3 to the atmosphere. In the absence of exogenous inputs, NH4+ in soils is derived from the mineralization of soil organic N. Loss of NH3 is affected by the rate of nitrification, cation exchange and biotic immobilizations that compete for NH4+. Plant growth in many desert ecosystems is limited by available N during the wet season, and gaseous losses of N represent an important potential loss of soil fertility. We have examined the processes controlling the loss of gaseous NH3 from Chihuahuan Desert soils.

We hypothesized that if the rate of nitrification limits the loss of NH3 from desert soils, then the rate of NH3 volatilization should increase when nitrification is inhibited experimentally. Similarly, if microbial immobilization of NH4+ inhibits the loss of NH3, then the

loss of NH3 should decline when labile organic C is added. If the availability of NH4+ determines the loss of NH3, then losses should increase when NH4+ is added or when added water stimulates the rate of N mineralization from native organic matter.

Ammonia volatilization was measured at three sites in the Chihuahuan Desert of southern New Mexico, U.S.A. In dry soils, ammonia volatilization ranged from 9 to 11 micrograms of nitrogen per square meter per day, but rates increased to 95 micrograms of nitrogen per square meter per day in a shrubland site after an experimental addition of water. Ammonia volatilization also increased with experimental additions of NH4Cl and decreased with additions of sucrose. Competition by nitrifiers for available NH4+ had little effect on NH3 volatilization: N-Serve, added to inhibit nitrification, decreased NH3 volatilization in a grassland site and had little effect at other sites. We suggest that NH3 volatilization is controlled by the rate of mineralization of NH4+ from soil organic matter, and mineralization is stimulated by rainfall. Overall rates of NH3 volatilization from undisturbed desert ecosystems appear to be much lower than those reported for rangeland and agricultural soils.

10) Date set(s) associated with project:

Data set name	Documentation file name
Ammonia volatilization-1988	NH3VOL88.DSD
Ammonia volatilization-1989	NH3VOL89.DSD

11) Publications resulting from project research:

Schlesinger, W. H. and W. T. Peterjohn. 1991. Processes controlling ammonia volatilization from Chihuahuan Desert soils. Soil Biology & Biochemistry 23(7):637-642

12) Comments (Include any comments that here that more full describe this project):

<NONE>

13) Project file history log:

Project title - Ammonia volatilization
Project file name - NH3VOL.PRJ

mm/dd/yyyy - Date of comment (month/day/year)
Int - Initials of person making comment
Changes/Updates - List any changes made to document

KJL - Kevin J. La Fleur
JPA - John P. Anderson

mm/dd/yyyy	Int	Changes/Updates
06/05/1996	JPA	Project documentation completed from provided data file.
07/05/1996	JPA	Converted project document file to new format.

END OF PROJECT FILE

Jornada LTER GIS Archive

General Feature and Boundary Locations

Boundary of Jornada Basin
Boundary of USDA Jornada Experimental Range
USDA JER pasture fences
USDA JER exclosures
USDA JER wells
USDA JER roads
Boundary of CDRRC
CDRRC pasture fences
CDRRC exclosures
CDRRC watering points (wells, tanks
CDRRC roads

Climate Network Locations

LTER aeolian weather station
LTER biodiversity study raingauge
CDRRC raingauges
LTER hydrology flume raingauges
USGS weather station
IBP tipping bucket raingauge
USDA JER headquarters weather station
USDA JER standard raingauges
USDA JER recording raingauges
LTER weather station
LTER NPP graduated raingauges
LTER PColl weather station
LTER Upper Trailer tipping bucket raingauge

Digital Elevation Model

24 7.5-minute digital elevation models
Basin Digital Elevation Model
Basin Shaded Relief

Vegetation

1930's Vegetation Map Buffington and Herbel
1982 Vegetation Cover Map SDSU
Multitemporal TM Vegetation Classification Univ of Wisconsin

Soils

Dona Ana County Soil Survey
Desert Soils Project

Geology

Geology Map of the San Andres Mountains, New Mexico

LTER Research Locations

Animal Transects
Arthropod Pitfall Traps II
Arthropod Pitfall Traps III
Lizard Pit Fall Traps
Small Mammal Traps
Small Mammal Exclosures
Termite Baits
Fine Litter Decomposition (LIDET)
Groundwater Recharge
Net Primary Production Plots
Transects
Ammonia Volatilization
soil geomorph
Stressor I
Stressor II

USDA ARS JER Research Locations

Permanent Quadrats
Lagomorph Study

Jornada LTER Image Archive

IMAGES		1987	1988	1989	1990	1992	1993	1994	1995	1996	1997
AVHRR		Mar 4	Mar 15	Feb 22	Mar 19	Mar 15	Mar 5				
		Mar 10	Mar 21	Mar 17	Apr 14	Apr 8	Mar 24				
		Mar 24	Apr 12	Apr 4	May 6	Apr 22	Apr 11				
		Mar 29	Apr 26	Apr 18	May 20	Apr 30	Apr 26				
		Apr 1	May 15	May 2	Jun 2	May 16	May 20				
		Apr 15	Jun 7	May 19	Jun 23	Jun 3	Jun 2				
		Apr 30	Jun21	Jun 7	Jul 7	Jun 12	Jun12				
		May 28	Jul 13	Jun 20	Jul 28	Jun 30	Jul 5				
		Jun 15	Jul22	Jul 2	Aug 24	Jul 6	Jul 24				
		Jun 24	Aug 14	Jul 4	Sep 11	Jul 19	Aug 11				
		Jul 8	Sep 7	Jul 22	Sep 25	Aug 3	aug 15				
		Jul 27	Sep 25	Aug 9	Oct 11	Aug 22	Sep 3				
		Aug 18	Oct 8	Aug 22		Sep 10	Sep 18				
		Aug 31	Dec 1	Sep 4		Sep 29	Sep 26				
		Sep 23		Sep 18		Oct 13	Oct 21				
		Oct 6		Oct 10							
		Oct 16		Oct 28							
				Dec 3		Also bi-weekly composites for 1991-1993					
AVIRIS											May 27
Daedalus								Sept 17			
								Sept 18			
Landsat TM						July 6	May 30	Mar 27	Jun 5	Feb 16	May 25
						Aug	Jul 6		Sep 25		
						Sept	Sept 3				
							Oct 5				
ATLAS								May 27			
SAR							May 19				

JORNADA LTER DATA REQUEST LOG

SentBy: JA = John Anderson KL = Kevin La Fleur BN = Barbara Nolen
LH = Laura Huenneke

Format: D=diskette E=email F=ftp H=hardcopy

RecBy	Date of Request mm/dd/yy	DateSent mm/dd/yy	RequestBy	RequestDescription	DataFromFile	FileSize	Format	SentBy
KL	10/03/94	10/07/95	Matt Hohmann	Transect Plant Line Intercept	FALL.DAT	395	D	KL
			Ohio St. Univ.	OCT82, OCT83, SEP84				
JA	10/21/94	10/21/94	Ted Floyd	Monthly air(min,max,avg), precip	WSDAYAL.DBF	2	E	JA
			Penn St. Univ.	Apr-Aug 93 & 94				
JA/KL	10/20/94	10/25/94	Leslie Sieger	Jornada LTER keyword listing		125	E	KL
			Colorado St. Univ.	Jornada bibliography		191	E	KL
JA	11/21/94	11/21/94	Kay Gross	Jornada LTER plant species list		114	E	JA
			KBS	Listing: alpha and family				
JA	12/06/94	12/09/94	Bob Waide	Long term data set list		2	E	JA
			r_waide@upr1.upr.clu.edu					
KL	01/02/95	01/06/95	Walt Whitford	Data set doc for Animal Transect,		77	D	KL
			EPA	Lizard and Arthropod pitfalls				
JA	01/10/95	01/10/95	Mike Atchley	Air temp & precip		10	D	JA
				Jun-Sep 92-94				
KL/JA	01/25/95	01/30/95	Peter Herman	Transect soil H2O content &	SWP8687.DAT	9	E	JA
			NMSU	soil H2O potential	SWC8687.DAT			
JA	01/30/95	02/06/95	Kirk Maloney	Jornada bibliography	JRNLTER	191	F	JA
			Iowa State Univ.					
JA	01/31/95		Ben Sherman	Jornada bibliography				
			University of WI	[Waiting for Sherman response				
				on file format and destination]				
JA	02/03/95	02/07/95	Adrienne Pilmanis	Monthly summary climate data	WSDAYAL.DBF	18	E	JA
			Duke	1983-1994				
KL	02/03/95	03/14/95	Debbie Hartell	USDA/NOAA evap pan	EVAP6274.DAT	220	D	KL
			Holloman AFB	1962-1974	EVAP6274.HIS			
JA	03/07/95	03/07/95	Chris Tripler	Jornada bibliography	JRNLTER	191	E	JA
			Idaho St. Univ.					
JA	03/14/95	03/14/95	Jeff Straka	Jornada playa invertebrate citations		3	E	JA
			Iowas St. Univ.					
JA/KL	03/15/95	03/16/95	Wes Jarrell	Transect SWC	TRNSWC##.DAT	8889	D	KL
			Graduate Research Inst.	(soil water content)				
			Beaverton, OR					
JA	04/03/95	04/04/95	Judith Lancaster	Pub: LTER in the U.S. - A	NA	NA	H	JA
			Desert Research Institute	Network of Research Sites				
			Univ of NV	1991				
JA	04/25/95	05/01/95	Anne Hartley	Precip @ Upper Trailer	JRN_TERM.DAT	18	E	JA
				Jun-Sep 92-94				
JA	04/28/95	04/28/95	Keith Killingbeck	Precip for U.T. (85-95) &	JRN_SUM.DAT	26	D	JA
			Univ of RI	C-CALI (89-95)	TERMCALI.ORG			
JA	05/15/95	05/16/95	Sarah Valentine	Jornada LTER plant list		61	E	JA
			McBeans@io.com					
JA	05/19/95	05/29/95	Ben Sherman	Jornada bibliography	JRNLTER2	182	E	JA

			ben@allstenex.botany.wisc					
			.edu					
JA	05/31/95	05/31/95	Troy Jamison for Whitford	Jornada bibliography	JRNLTER2	1891	D	JA
			(picked up)	(Procite format)				
KL	06/30/95	06/30/95	Rick Miller (NMSU)	USDA/NOAA Temp/Precip	CDNOAA.DAT	3	H	KL
KL	07/21/95	07/21/95	Laura Huenneke (NMSU)	NPP Harvest for 1993	NPPR93W.BK1-BK3	103	D	KL
JA	09/12/95	09/13/95	Danielle Carlock	Jornada bib (playa citations)	JRNLTER2	10	H	JA
JA	10/02/95	10/03/95	Mark Dunn (Sol Ross Univ)	NOAA-USDA climate data (1913-1993)	CDNOAA-E.DAT	77	E	JA
				Monthly summary: rain,temp,evap				
KL	10/30/95	10/30/95	Dr. Whitford (EPA)	Precip @ Upper Trailer	JRN_SUM.DAT	6	E	KL
				Monthly summary 1989-1994				
KL	10/30/95	10/30/95	Leigh Murray	Precip @ Upper Trailer	JRN_SUM.DAT	6	D	KL
				Monthly summary 1989-1994				
LH	10/??/95	10/??/95	B. Schlesinger/Sean Connin	Mean biomass for 15 NPP sites		7	H	
JA	11/12/95	11/14/95	Cheryl Craddock	JRN biblio citations on plants	JRNLTER2	30	E	JA
JA	12/20/95	12/21/95	Joe Johnson	50cm&100cm soil temp for 84,85,94,95	WSHOURAL.DBF	430	D	JA
			Pipeline Safety Dept.	for Jun-Sep for each year.				
			State Corporation Commission					
			P.O. Drawer 1269					
			Santa Fe, NM 87504					
			505-827-3774					
JA	02/07/96	02/07/96	Walt Whitford	Precip @ Upper Trailer	JRN_SUM.DAT	6	E	JA
				Monthly summary 1989-1994				
JA	02/27/96	03/04/96	George Hess (Duke Univ.)	NOAA-USDA climate data (1913-1993)	CDNOAA-E.DAT	77	E	JA
			Post-doc w/ Reynold's	Monthly summary: rain,temp,evap				
JA	03/14/96	03/14/96	Anne Hartley (Duke Univ.)	Daily temp & precp (Jun-Au				
g95)	WSDAY96.DAT		7 E JA					
JA	03/14/96	03/15/96	George Hess (Duke Univ.)	Abstracts to 3 NMSU, Biology theses	JRNBIB	10	E	JA
JA	03/27/96	04/01/96	John Wiens	Bird, herp, mammal, & plant lists	bird.txt	11	E	JA
					herp.txt	4	E	JA
					mammal.txt	3	E	JA
					plntalfa.txt	66	E	JA
JA	04/16/96	04/16/96	Mike Atchley	NPP monthly precip 92-95(CALI,SAND,	jrn_npp.dat	26	F	JA
				GRAV,BASN,SUMM)				
JA	04/26/96	04/26/96	Mahlia Nash	LTER W.S. daily data for 1996	wsdayal.dbf	7	E	JA
JA	04/29/96	04/29/96	Jan Hendricks	Jornada bib citations (H2O&nutrient)	jrnbib	26	E	JA
LH	04/??/96	04/??/96	Adrienne Pilmanis	NPP biomass & relative abundance		7	E	LH
				of spp at grassland & mesquite sites				
JA	05/19/96	05/20/96	Tom Crist/Carl Friese	Jornada bib citations (C,N,&P)	jrnbib	26	E	JA
JA	06/28/96	06/28/96	John Wainwright	LTER Upper Trailer daily precip.	lter-ut.dat	14	F	JA
JA	06/28/96	06/28/96	John Wainwright	LTER W. S. daily precip.	lter-ws.dat	26	F	JA
JA	06/28/96	06/28/96	John Wainwright	LTER USDA NOAA daily precip.	usda.dat	51	F	JA
JA	07/19/96	07/25/96	John Frey(UNM)	USDA standard rain gage network data	usdacan.exe	2631	E	JA
JA	08/03/96	08/05/96	Anne Hartley(Duke)	NPP standard rain gage data	prec_npp.dat	33	E	JA
JA	09/10/96	12/09/96	Christine Mann(Ft.Collins)	Thermocouple temp(air,1,5,10,20,50,	wshoural.dbf	7553	F	JA
				100,200 cm)				
JA	09/10/96	12/09/96	Christine Mann(Ft.Collins)	Surface soil temperature	wshoural.dbf	2235	F	JA
JA	09/10/96	12/09/96	Christine Mann(Ft.Collins)	Thermocouple temp(400,600,880cm)	wshoural.dbf	1576	F	JA
JA	09/10/96	12/09/96	Christine Mann(Ft.Collins)	Air temp (thermistor)	wshoural.dbf	984	F	JA
JA	09/10/96	12/09/96	Christine Mann(Ft.Collins)	Soil temp @ 20cm (thermistor)	wshoural.dbf	349	F	JA
JA	11/20/96	12/11/96	Roberto Fernandez(Duke)	Precip(1972-1996, Weather Station)	wsdayal.dbf	99	E	JA
JA	11/20/96	12/11/96	Roberto Fernandez(Duke)	Precip(WS_PCOLL Weather Station)	wsdayal.dbf	6	E	JA
JA	11/20/96	12/11/96	Roberto Fernandez(Duke)	Precip(LTER-I&II Hydology runoff)	jrn_hyd.dat	244	E	JA
JA	11/20/96	12/11/96	Roberto Fernandez(Duke)	Daily max/min air temperature)	wsdayal.dbf	136	E	JA
JA	11/20/96	12/11/96	Roberto Fernandez(Duke)	USDA Daily max/min air & precip)	cdnoaa.dbf	222	E	JA

JA	11/20/96	12/11/96	Roberto Fernandez(Duke)	USDA Daily max/min air & evap)	cdnoaa.dbf	156	E	JA
JA	02/20/97	02/20/97	Geoffrey Carpenter	Jornada vertebrate list(bird&mammal)	birdcomn.lst	11	E	JA
JA	02/20/97	02/20/97	Geoffrey Carpenter	Jornada vertebrate list(bird&mammal)	mammal.lst	3	E	JA
JA	03/10/97	03/10/97	Athol Abrahams	LTER-3 flume H2O & GRG data	flumeht.dat	7	E	JA
JA	03/10/97	03/10/97	Athol Abrahams	LTER-3 flume H2O & GRG history	flumeht.his	5	E	JA
JA	03/10/97	03/10/97	Athol Abrahams	LTER-3 detailed TBRG for north flume	flumen76.dat	29	E	JA
JA	03/10/97	03/10/97	Athol Abrahams	LTER-3 detailed TBRG for south flume	flumes85.dat	26	E	JA
JA	03/12/97	03/12/97	David Lightfoot	NPP biomass summary	nppmass.sum	3	E	JA
JA	03/12/97	03/12/97	David Lightfoot	NPP seasonal production summary	nppprod.sum	3	E	JA
JA	03/12/97	03/12/97	David Lightfoot	NPP annual production summary	annprod.sum	2	E	JA
JA	03/12/97	03/12/97	David Lightfoot	NPP GRG rain data	jrn_npp.dat	64	E	JA
JA	03/19/97	03/19/97	Chris Tripler(Idaho St U)	Bib citations: plant&soil N from -->	jrnltern.dat	16	E	JA
JA	03/19/97	03/19/97	Laura Gough (Woods Hole)	Upper Trailer precip summary	up_prec.sum	19	E	JA
JA	03/26/97	04/01/97	Steve Hager (NMSU grad)	HOMA lizard distribution	lizrdpit.dat	3	H	JA

Jornada LTER Spatial Information Request Log

Date of Request	Date Fulfilled	Requestor	Institution/Agency	Request Description
10-13-95	10-13-95	Adrienne Pilmanis	Duke University	Research site map
11-07-95	11-10-95	John Wainwright	Kings College, London	GIS archive coverages
11-08-95	11-27-95	John Wainwright	Kings College, London	Landsat TM Image
11-26-95	12-12-95	Eddie Garcia	USDA JER	GIS archive coverages of USDA
11-27-95	01-03-96	Kris Havstad	USDA JER	Permanent quadrat location map
01-03-96	03-25-96	Bob Gibbens	USDA JER	Permanent quadrat overlay maps 1:21000
01-09-96	01-12-96	Ted Floyd	Williams College, Mass	Research site maps
01-10-96	02-02-96	Rob Parry	USDA ARS Hydrolab	Daedalus image transferred to Hydrolab
01-12-96	02-15-96	Cheryl Craddock	Univ of Connecticut	Maps and aerial photos of research plots
02-05-96	02-08-96	Cathie Sandell	NMSU Biology	Coordinates for LTER animal transects and NPP sites
02-08-96	02-08-96	Rob Parry	USDA ARS Hydrolab	Coordinates of Jornex95 met locations
02-12-96	02-15-96	Curtis Monger	NMSU Agronomy	Soil mapping project boundary and image overlay
02-15-96	02-20-96	George Hess	Duke University	DEM, historic vegetation coverage transferred to Duke
02-19-96	03-27-96	Johannie Herrera-Matos	NMSU Biology	Research site maps
03-07-96	03-10-96	Jerry Ritchie	USDA ARS Hydrolab	Process GPS data
03-07-96	03-15-96	Sean Connin	Dartmouth College	Map of percent cover of species in dune areas
03-25-96	04-18-96	Greg Okin	Caltech	TM image transferred to Caltech
03-18-96	03-27-96	Hilda Taylor	Univ of Texas El Paso	Maps
04-03-96	05-22-96	Bob Gibbens	USDA ARS JER	Map overlays of permanent quadrat locations 1:16000
04-04-96	05-01-96	Craig Dobson	Univ of Michigan	DEM and vegetation coverage
04-12-96	05-13-96	John Weins	Colorado State	Maps of soils and vegetation
04-18-96	05-08-96	Kris Havstad	USDA ARS JER	Maps for ARS review tourbook
05-05-96	06-02-96	Adrienne Pilmanis	Duke University	Large scale maps of reflectance values, in 3 bands
05-16-96	05-16-96	Josef Kellendorfer	Univ of Michigan	Create NPP polygons and transfer coverages
05-16-96	07-06-96	Susan Langley	Univ of Oklahoma	GCP coordinates for georegistering imagery

05-21-96	05-23-96	Fenton Kay	USDA ARS JER	GPS base station files
05-30-96	06-10-96	Jerry Ritchie	USDA ARS Hydrolab	Jornada locator map in tif format transferred
05-30-96	06-12-96	Sean Connin	Dartmouth College	locator map for study sites
06-04-96	06-05-96	Carol Evans	NMSU Wildlife	road coverage
06-07-96	07-17-96	Andrew French	USDA ARS Hydrolab	GPS coordinates of GCP's for georegistering TM scenes
07-01-96	07-28-96	Anne Hartley	Duke University	Maps of Jornada and research sites
07-11-96	08-12-96	David Howes	SUNY Buffalo	Large scale maps resesarch sites
07-12-96	07-16-96	Greg Okin	Caltech	GIS and Image archive list
07-15-96	07-19-96	John Wainwright	King's College, London	GPS coordinates of research rills
08-01-96	08-06-96	Ross Virginia	Dartmouth College	Map of Jornada in relation to Chihuahuan Desert
08-14-96	08-20-96	Tamara Hockstrasser	Colorado State Univ	theodolite equipment and gps of research sites
08-28-96	09-10-96	Greg Okin	Caltech	grazing history, vegetation, CDRRC fences, wells etc
08-28-96	09-05-96	Ed Frederickson	USDA ARS JER	Sludge project maps with overlays
01-09-97	01-15-97	Jeff Herrick	USDA ARS JER	maps of ant infiltration study
01-09-97	01-30-97	Esteban Muldavin	Nature Conservancy	digital photos of M Nort, C Grav, G Basn
01-09-97	01-15-97	Bob Gibbens	USDA ARS JER	maps of soil pits
01-23-97	02-10-96	Jennifer Peterson	Dartmouth College	coverages of vegetation soils and dem
01-24-97	01-25-97	Laura Huenneke	NMSU Biology	NPP map
01-30-97	02-03-97	Paul Hyder	USDA ARS JER	Detail map of Middle Well
02-10-97	02-11-97	Abdullah Faizur Rahman	University of Arizona	GIS archive coverages
02-11-97	04-23-97	Brandon Bestelmeyer	Colorado State Univ	Gps and map of ant transects
03-10-97	03-20-97	Alan Johnson	NMSU JER	Maps of study site and Chihuahuan desert
03-12-97	03-18-97	John Wainwright	King's College, London	Digital elevation model with sample points
03-14-97	03-17-97	Mike Sipos	NMSU	coverage of roadsm streams, raingagesm dem
04-02-97	04-03-97	Dean Anderson	USDA ARS JER	map of USDA pastures 7B and 7C
04-04-97	04-05-97	Peter Herman	NMSU Biology	Map of NPP locations with roads and pastures
04-17-97	04-29-97	Patti Dappen	NMSU Geography	Soils coverage
05-12-97	05-16-97	Josef Kellendorfer	Univ of Michigan	Coverage of NPP sites
05-27-97	05-29-97	David Howes	SUNY Buffalo	coverages of roads, pastures hydrology plots
06-06-97	06-16-97	Eddie Garcia	USDA ARS JER	Map of proposed fiberoptic line

Papers Published (66) and In review/In press (40) as part of the Jornada LTER-III

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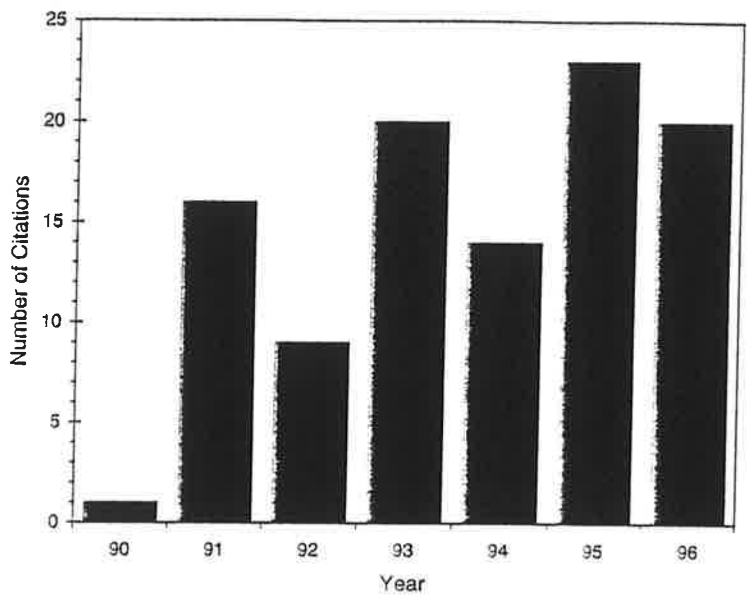
The organizing hypothesis of the Jornada LTER was first presented in a paper that appeared in SCIENCE, under the coauthorship of the principal investigators (paper follows here). We regard that paper as seminal, and an analysis of its citations since 1990 shows its continuing impact on the general field of desertification.



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Biological Feedbacks in Global Desertification

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Biological Feedbacks in Global Desertification

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Studies of ecosystem processes on the Jornada Experimental Range in southern New Mexico suggest that long-term grazing of semiarid grasslands leads to an increase in the spatial and temporal heterogeneity of water, nitrogen, and other soil resources. Heterogeneity of soil resources promotes invasion by desert shrubs, which leads to a further localization of soil resources under shrub canopies. In the barren area between shrubs, soil fertility is lost by erosion and gaseous emissions. This positive feedback leads to the desertification of formerly productive land in southern New Mexico and in other regions, such as the Sahel. Future desertification is likely to be exacerbated by global climate warming and to cause significant changes in global biogeochemical cycles.

Climate models suggest that during the next century the average values of temperature and precipitation are likely to change over large areas of the globe. As a result, widespread adjustments are likely to occur in the distribution of terrestrial vegetation. Changes in global climate due to increasing concentrations of greenhouse gases may be supplemented by changes driven by the deforestation of tropical regions, particularly in the Amazon Basin. Tropical forests and arctic regions have been the focus of much attention; however, changes in other areas are expected as well. Emanuel *et al.* (*1*) predicted a 17% increase in the world area of desert land during the climate changes expected with a doubling of atmospheric CO_2 content. Any directional shift to a greater area of arid land potentially represents a permanent loss in the productive capacity of the biosphere on which all life depends (*2*). In this article, we focus on changes that can be expected at the transition between semiarid and arid lands and on the potential for an increasing area of arid land—desertification—to alter biogeochemical processes at the global level.

No explicit definition exists for the concept of desertification (*3*). Areas that have been arid during the last several centuries cannot be said to have become "desertified," even if they are now also affected by human exploitation. Historical evidence indicates that natural climatic patterns produce cycles of drought, followed by periods of relatively higher rainfall (*4*). Losses of agricultural productivity and the associated social and economic disruptions during drought cannot be said to represent desertification unless the landscape is so altered that a full recovery during relatively moist conditions is impossible. When a long-term change in ecosystem function has been observed in arid lands, direct intervention by humans, rather than climatic change, usually appears to be responsible (*5, 6*), although there are clear exceptions (*7*).

Several climate models suggest that future global warming may reduce soil moisture over large areas of semiarid grassland in North America and Asia (*8*). This climate change is likely to exacerbate the degradation of semiarid lands that will be caused by rapidly expanding human populations during the next decade (*9*). Because marginal areas are particularly sensitive to change, studies of ecosystem function at the transition between semiarid and arid ecosystems offer an effective index of human perturbation of the global system.

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Conceptual Models for Desertification

We suggest that the changes in ecosystem function at the transition between arid and semiarid regions are best understood in the context of the spatial and temporal distribution of soil resources. In our hypothesis, when net, long-term desertification of productive grasslands occurs, a relatively uniform distribution of water, N, and other soil resources is replaced by an increase in their spatial and temporal heterogeneity. This heterogeneity leads to the invasion of grasslands by shrubs. In these new plant communities, soil resources are concentrated under shrubs, while wind and water remove materials from intershrub spaces and transport soil materials to new positions on the landscape (*10*). Our hypothesis is based on studies in the Jornada Experimental Range of southern New Mexico, but we believe that this model applies to desertification in other areas of the globe.

The Jornada Experimental Range comprises 78,266 ha of the Chihuahuan Desert, which extends from the south-central United States to central Mexico. In our study area, mean annual temperature is 15.6°C and mean precipitation is 21 cm $year^{-1}$, with 53% of the precipitation occurring from July to September (*11, 12*). During the last 100 years, large areas of black grama (*Bouteloua eriopoda*) grassland have been replaced by communities dominated by shrubs, especially creosote bush (*Larrea tridentata*) and mesquite [*Prosopis glandulosa* (*12, 13*)]. Similar shrub invasion in formerly productive grasslands has occurred in a large area of western Texas and eastern New Mexico that represents the transition between semiarid and arid lands in North America (*14*).

Black grama grassland is shallow rooted, with seasonal patterns of photosynthesis closely coupled to the availability of soil moisture (*15, 16*). Infiltration of incident rainfall is enhanced under black grama because a complete canopy cover lowers the effective energy of raindrops (*17*). A large percentage of the incident rainfall enters

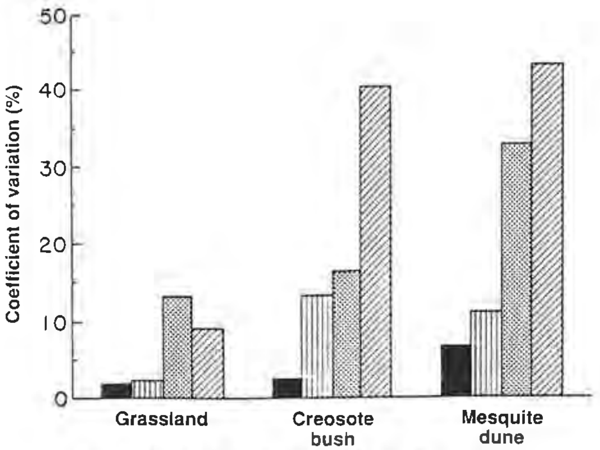

Fig. 1. Coefficient of variation associated with mean values for soil properties measured in 200 samples taken in each of three habitats on the Jornada Experimental Range (*105*). Bars are represented as follows: solid, *p*H; parallel lines, saturation percentage; dotted, soil moisture; and diagonal lines, total N.

the soil, and horizontal transport of water and nutrients in runoff is infrequent (*18*). Although soil moisture varies seasonally with rainfall, high infiltration is thought to result in a relatively uniform horizontal availability of soil water (Fig. 1) (*19*). Uptake and transpiration losses of soil moisture by black grama are closely coupled to input (*15, 20*), so that the soil rarely receives moisture at great depth, and most biotic processes are confined to the upper soil layers (*21*). Mineralization and uptake of N occur primarily in the top 30 cm of the soil profile (*22, 23*).

Large herds of domestic livestock disrupt this tight connection of soil and plant processes and lead to a decline in the cover of black grama and other species in semiarid grasslands. Heavy grazing during the short summer wet season contributes to the loss of grass cover during moderate drought and to lowered competitive potential of grasses (*24*). Trampling compacts the soil and reduces infiltration rates (*25*). Greater runoff results in erosion and increased transport of water, N, and other plant nutrients between geomorphic units in the basin. The net effect of these changes is to reduce the availability of soil moisture and nutrients in the landscape and to increase the heterogeneity of their horizontal distribution.

The redistribution of water by overland flow results in heterogeneity in the spatial distribution of soil moisture. We suggest that the cover of shrubs increases as a direct result of nonuniform distributions of water in space and time. Shrubs can exploit the additional soil moisture that infiltrates under intermittent streambeds and in local areas where water accumulates during runoff. Shrub cover and net primary production are often greatest in these areas (*26*). In large areas of the Mojave Desert in which overland flow has been diverted for 45 years, Schlesinger and Jones (*27*) showed that shrub biomass and density were significantly lower and the cover of perennial grasses was greater than in adjacent areas that received runoff.

Shrub dominance leads to a further heterogeneity of soil properties because effective infiltration of rainfall is confined to the area under shrub canopies (*28*), whereas barren intershrub spaces generate overland flow, soil erosion by wind and water, and nutrient loss (*29*). Runoff removes an average of 20% of the incident precipitation that falls in creosote bush desert (*30*). The cycling of plant nutrients, largely controlled by biotic processes in any ecosystem, is progressively confined to the zone beneath shrubs; this process leads to the development of well-known "islands of fertility" that characterize desert shrublands (*31, 32*). Initially these islands may not represent local accumulations of nutrients as much as remnants of the original homogeneous and fertile soil of the grassland ecosystem. In time, the islands of fertility become favored sites for shrub regeneration (*33*) and yield self-augmented levels of local fertility. One measure of the degree of development of local patches of fertility is the coefficient of variation in soil N. In the study area on the Jornada Experimental Range, the coefficient measured in 200 samples taken at 1-m intervals along a transect was about four times as great in areas dominated by creosote bush and mesquite as in relict areas of black grama grassland (Fig. 1).

Such changes alter not only the local distribution of soil resources but also the extent and location of other ecosystem processes in the landscape. Erosion of soil from intershrub areas results in a greater horizontal transport of nutrients in runoff, which may then result in greater rates of denitrification and ammonia volatilization in the heavy soils that accumulate in basin depressions, known as playas. The overall amount of N loss from the basin may rise as runoff transports N between landscape positions. The N that enters the ecosystem in areas of mesquite, which engages in symbiotic fixation of atmospheric N, may now be transported to sites where it can be lost through the production of reduced gases.

Although desertification is often assumed to result in a reduced level of plant growth, net primary productivity is similar in the native grasslands and the invasive shrub communities in southern New Mexico (*26*). However, changes in the quality of net primary production with shrub invasion lower the economic potential of the landscape, especially as rangeland. Thus, total net primary production may not always be the best measure of the desertification process. As an alternative, changes in soil properties may be a general measure of the changes in ecosystem function that underlie various forms of desertification.

Feedback Processes

Our studies in southern New Mexico provide a model that can be used to link processes in dryland ecosystems to the global level (Fig. 2). Aspects of the model reflect the concept of Charney (*34*) of a biogeographical feedback leading to increasing global desertification, but important details have been modified by more recent work. Because the removal of soil moisture by the transpiration of semiarid grassland is greater than in shrubland or bare ground (*20, 35*), there is greater cooling of the soil in grasslands by the loss of latent heat. As grassland is replaced by shrubland and a greater percentage of the soil is bare, soil surface and air temperatures increase, even though the albedo of exposed desert soil is greater (*36, 37*). Higher surface temperatures promote thermal circulation of the atmosphere, but there is lower relative humidity and precipitation. Hot, dry soils retard the accumulation of organic N in the soil, and thus further promote the spread of shrubland in which plant growth is less closely tied to N turnover in the surface soils. As these abiotic factors predominate over biotic factors, the balance tips further in favor of the development of arid ecosystems. This transition may result from direct human exploitation, as in southern New Mexico, or from indirect causes, such as global climate change (*8*). Once begun, the increasing heterogeneity of soil resources in arid lands is likely to develop a positive feedback that will reinforce the new functional properties of the ecosystem.

A large increase in the area of arid lands may affect processes at the global level. For example, desertification of the Sahelian region of West Africa may increase the regional albedo by as much as 4% (*38, 39*). Such changes in radiation balance are likely to affect regional climate and potentially lead to further decreases in regional rainfall (*40*). Other effects include the long-range transport of materials and a greater contribution of arid lands to global biogeochemical function.

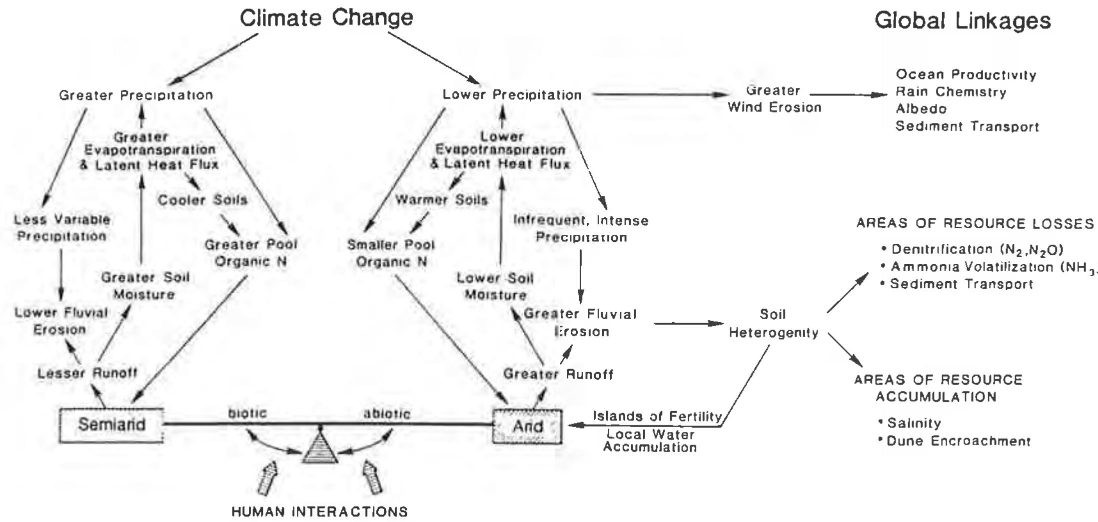

Fig. 2. A model linking changes in ecosystem properties during desertification to changes in global biogeochemistry.

Biogeochemistry in Deserts

Understanding the function of desert ecosystems in the context of limited moisture as the single controlling factor has diverted attention from an equally important role of N in determining plant productivity (*41, 42*). In addition, arid soils frequently show accumulations of calcium carbonate (caliche) that buffer soil *p*H in the range of 7 to 8, and complex P in unavailable forms (*23, 43*). In response to deficiencies of N and P, *Larrea tridentata* in southern New Mexico shows some of the highest levels of nutrient use efficiency that have been found in woody plants (*44*). Losses of soil N that are associated with the transition from grassland to desert may result in an environment that favors N-fixing shrubs, such as mesquite, which augment local levels of fertility (*32*).

The limited nutrient supply in desert soils is not the result of slow nutrient cycling. Decomposition in deserts is surprisingly fast (*45*) and is driven by an abundant soil microfauna that contributes to nutrient turnover (*46*). Relatively rapid turnover in desert soils leads to low levels of nutrient accumulation (*47*) and to potential losses of available nutrients from the ecosystem (*48*). For desert soils of the southwestern United States, Peterjohn (*49*) has developed a mass balance model for N during the Holocene period (Table 1). In his model, more than 77% of the N deposited during the last 10,000 years has been removed from desert ecosystems, and most of that must have been lost to the atmosphere because river transport to the ocean and deep seepage to ground water are minimal (*50*). Ammonia volatilization, denitrification, and wind erosion contribute to losses of N from deserts, and all of these processes are likely to increase when grasslands are converted to desert shrubland.

Table 1. A N budget for desert ecosystems of the southwestern United States during the last 10,000 years. All data are in kilograms of N per square meter (*49*).

Process	Flux
Atmospheric input	2.99
Accumulation	
Vegetation	0.036
Soil	0.604
Total	0.640
Output	
Runoff	0
Deep seepage	0.028
Total	0.028
Inferred loss to the atmosphere	2.32

In soils of high *p*H, ammonium is converted to NH_3, which is lost to the atmosphere by the reaction

$$NH_4^+ + OH^- \rightarrow NH_3\uparrow + H_2O$$

This reaction is favored in alkaline soils, and the loss of NH_3 is maximized in dry permeable soils with low cation exchange capacity (*51*). Dawson (*52*) used a model of soil N transformations to estimate that the flux of NH_3 from nonagricultural lands of the world was 47×10^{12} g year^{-1}, including 21.8×10^{12} g year^{-1} from the latitudinal belts between 20° and 40°, which contain most of the world's arid lands.

The loss of ammonia to the atmosphere is especially significant because ammonia is the only substance capable of generating alkalinity in rainfall (*53*). Ammonia has a short lifetime in the atmosphere, and undoubtedly some of the flux from arid regions is deposited locally. However, because of the low rainfall in desert regions, a significant amount of NH_3 is likely to undergo long-range transport. This NH_3 can potentially neutralize acid rain in areas that are downwind of deserts. As early as 1958, Junge (*54*) noted high concentrations of NH_4 in the rainfall of the southwestern United States, and during our study in southern New Mexico, NH_4 concentrations were greater in rainfall collected in the summer, when NH_3 volatilization should be greatest (Fig. 3), than at other times. The volatilization of NH_3 should increase as grassland soils erode and $CaCO_3$ is then exposed at the surface (Table 2).

Several studies suggest that denitrification is also an important process in the removal of N from desert soils (*55*). Westerman and Tucker (*56*) found that about 70% of the N from added NH_4 and 95% of the N from added NO_3 were lost to the atmosphere after 1 year under field conditions. Peterjohn (*49*) reported that denitrifying bacteria are optimally adjusted to the temperature and *p*H of desert soils, and levels of organic C and nitrate are often nonlimiting to in situ enzyme activity. Bursts of denitrification presumably occur during the moist conditions that prevail after rainstorms (*57*). In semiarid grasslands, competition with grasses for available nitrate and rapid plant uptake of soil moisture probably limit denitrification. When shrublands replace grasslands and greater overland flow transports NO_3 to basin depressions, greater levels of denitrification are expected. The fine-textured soils found in these areas promote anaerobic conditions for denitrification for long periods after rainfall (*58*). Bowden (*59*) suggests that one-third of the gaseous loss of N from terrestrial ecosystems to the atmosphere (283×10^{12} g of N per year) occurs in desert regions. To the extent that the product of denitrification is N_2O, deserts make a contribution to the atmospheric burden of a gas that is involved in ozone destruction and greenhouse warming (*60*).

Losses of desert soil to wind erosion are globally significant (*61*). The upper limit for global estimates of the long-range transport of desert dust is approximately 1×10^{16} g year^{-1} (*62*). If we assume that the N content of surface soils is about 0.064% (*49*), the total N loss from deserts as a result of wind erosion is 6.4×10^{12} g year^{-1}, or approximately 0.14 g m^{-2} year^{-1} from the world area of desert lands (4.6×10^9 ha) (*63*). About 40 to 70% of the atmospheric nitrate over the North Pacific Ocean is derived from continental aerosols (*64*), presumably from the deserts of China. Aerosols from the deserts of North America are likely to carry nitrate eastward and contribute to the dry deposition of N in forest vegetation (*65*).

Dust transport also affects the global cycles of S, P, and other elements. Wind erosion of desert soils that are rich in gypsum contributes to the content of SO_4^{2-} in rainfall (*66*), whereas erosion of soils rich in calcium carbonate contributes to the neutralization of acid components from anthropogenic activities (*67*) by reactions such as

$$CaCO_3 + H_2SO_4 \rightarrow Ca^{2+} + SO_4^{2-} + H_2O + CO_2 \uparrow$$

Young *et al.* (*68*) link this neutralization process to the strong correlation between Ca^{2+} and SO_4^{2-} concentrations in rainfall of the western United States, compared to the strong correlation between H^+ and SO_4^{2-} concentrations in the East (*69*). In North America, atmospheric deposition of Ca decreases from west to east (*70*), although a large dryfall of Ca is recorded as far east as Tennessee (*65*).

Wind erosion of desert soils confers an atmospheric component to the global cycle of P (*71*). A net P flux of 1×10^{12} g year^{-1} is transferred from continents to the oceans, and about half of this flux occurs as a result of the transport of dust from the Sahara to the North Atlantic. The net flux is only about 10% of the input of P to the oceans by river flow, but it is delivered to the central ocean basins where the P for net primary production is more limited than in continental shelf areas (*72*). More significantly, desert dust contains an appreciable content of Fe that may stimulate phytoplankton productivity in the oligotrophic waters of the central ocean. Martin and Gordon (*73*) reported that about 95% of the available Fe in the North Pacific Ocean is deposited from the atmosphere, where it is derived from the transport of desert dust from central China (*74*).

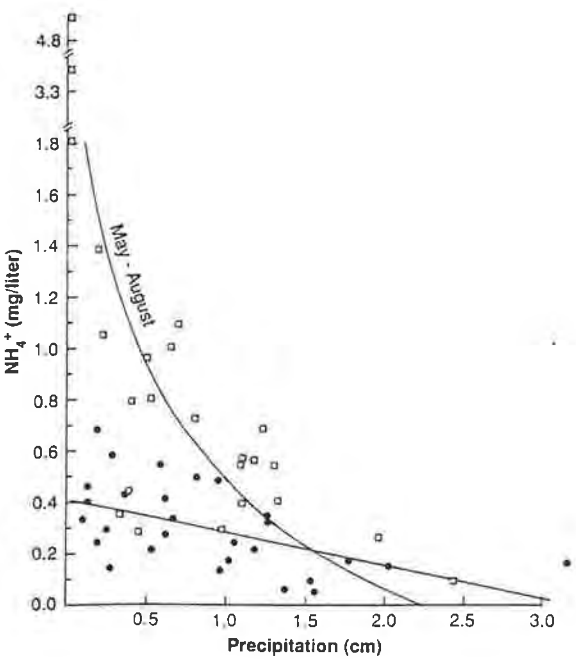

Fig. 3. Variation in the concentration of NH_4^+ in rainfall collected on the Jornada Experimental Range as a function of the volume of the precipitation event during 1987 through 1989 (*106*). Least-squares regression was used to fit a logarithmic relation to summertime (May through August) samples (□), in which concentration = $-1.44 \pm 0.215 \log_{10}(x) + 0.497$, $P < 0.0001$; and samples from other seasons (●), in which concentration = $-0.129 \pm 0.038\, x + 0.414$, $P < 0.0025$ (error limits are ± SE); x is the measured precipitation in centimeters.

Table 2. Ammonia volatilization in the Chihuahuan Desert of southern New Mexico during a drying sequence after application of simulated rainfall. All data are in micrograms of N per square meter per day (*106*).

Time (hours)	Grassland	Creosote bush	Playa
Pretreatment	15	15	43
24	45	95	50
48	35	30	34
168	21	24	20

Dust from arid regions makes a significant contribution to the burden of tropospheric aerosols (*53*). Although the effects of tropospheric aerosols are uncertain in detail, most types are thought to lead to climatic cooling (*75*), and thus they may offset the effects of increasing concentrations of greenhouse gases. In layers deposited during the last glacial episode, ice cores from Antarctica contain a large concentration of aerosols, which may have enhanced global cooling (*76*). These aerosols were derived from soils, and their abundance indicates that the global area of deserts and the wind erosion of desert soils may have been larger during the last ice age (*77*).

The climatic effects of tropospheric aerosols are determined by the optical properties of the particle and the albedo of the underlying surface (*36*, *75*). Over desert regions, soil dust may act to trap infrared reradiation from the earth's surface, and this trapping may lead to warming (*78*). An increasing flux of dust from deserts may lead to local warming in desert regions, while it cools other regions. Thus, an increase in the flux of soil dust from arid areas has the potential to exert widespread influence on global climate, but it is not clear exactly what those effects may be. In the future, satellite remote sensing may prove useful in tracking dust transport over large areas (*79*).

Contributions of arid lands to the atmospheric content of CH_4 and other hydrocarbons are poorly understood. Zimmerman *et al.* (*80*) suggested that there was a large CH_4 flux from termites, which are abundant in desert regions where they are important in the turnover of soil organic matter (*46*). The ant fauna of arid lands may contribute significant quantities of formic acid to the atmosphere (*81*), and desert shrubs emit a wide variety of volatile organic compounds (*82*). These emissions are subject to atmospheric reactions that produce ozone and other oxidizing substances (*83*). Studies suggest that arid and semiarid soils also release NO (*84*), which is closely involved in the production of tropospheric ozone.

Episodic Events

An increase in the desertification of marginal lands accentuates the importance of episodic events, such as torrential rainstorms and windstorms, in the control of ecosystem processes (Fig. 4). MacMahon and Wagner (*85*) have shown that the coefficient of variation associated with mean annual precipitation is greater in areas of low mean annual rainfall. An increased frequency of extreme rain events imposed on a landscape devoid of the protective cover of grassland leads to greater transport of soil materials during floods. As a result of catastrophic runoff events, lands at the margin of arid and semiarid regions typically show the highest annual rates of mechanical weathering (*86*) and high concentrations of suspended solids in rivers (*87*).

The transport of desert dust begins when wind velocity exceeds a critical threshold (*88*). Gupta *et al.* (*89*) showed that soil deflation from the Rajasthan Desert of India increases exponentially with increasing wind velocity. Deposition of dust in the cities of Kuwait is also exponentially related to the total wind flow (*90*). During synoptic weather patterns that are particularly conducive to the transport of dust, the total losses are often spectacular. Liu *et al.* (*91*) reported a dustfall of 1 g m^{-2} $hour^{-1}$ in Beijing, China, as a result of a single dust storm on 18 April 1980 in desert regions to the west. The frequency of dust storms is inversely related to mean annual rainfall (*92*), and there is evidence that dust storms have become more frequent as a result of human activities in semiarid lands (*93*). The frequency of episodic transport by wind and water from arid lands is also likely to increase in response to anticipated changes in global climate (*8*).

The increasing importance of episodic events also affects processes in the ecosystem. An environment where the recharge of soil moisture becomes less predictable and the surface layers are often dry selects for various species of shrubs that can exploit the recharge of deep soil layers that occurs in infrequent, torrential rainstorms (*94*). At first glance, the timing of plant growth in these areas will appear less coupled to rainfall (*16, 95*), but continued photosynthesis by shrubs during extended periods of drought is dependent on episodic rainfall that recharges the lower soil profile. In semiarid grasslands, growth is closely coupled to rainfall (*15*), but annual rainfall is greater and more predictable. Moreover, vegetation in semiarid grasslands can exploit soil moisture that is derived from small rain events (*96*). Rain use efficiency, defined as aboveground net primary productivity divided by annual rainfall, decreases strongly from semiarid grasslands to true deserts (*97*). Temporal heterogeneity in the availability of soil moisture reinforces the invasion of grasslands by shrubs.

The episodic availability of soil resources, especially moisture, leads to a "pulse-reserve" response of desert ecosystems (*98*). Primary production and soil nutrient turnover are greatest during periods of moisture availability, whereas ecosystem function during periods of drought depends on accumulated reserves. We suggest that during desertification, there is an increasing dependence of the biota on episodic, rich resources rather than more reliable, but low-level resources to which biotic activity can be closely coupled (*99*).

Conclusions

On the basis of the Jornada desertification study, we suggest that any process that leads to an increasing heterogeneity of soil resources in space and time is likely to lead to the degradation of semiarid regions, especially grasslands, and to the increasing spread of arid regions dominated by shrublands. Grazing increases soil heterogeneity in semiarid lands, and the conversion of these areas to shrub-desert is aided when cattle disperse the seeds of desert species such as mesquite (*14*). Similarly, greater soil heterogeneity caused by off-road vehicles leads to the degradation of desert areas by increasing the channelization of runoff and the rate of soil erosion (*100*). Conversion of semiarid grasslands to row-crop agriculture adds to local heterogeneity and is likely to lead to permanent desertification of these areas during future periods of drought.

Our view of the importance of soil properties is consistent with

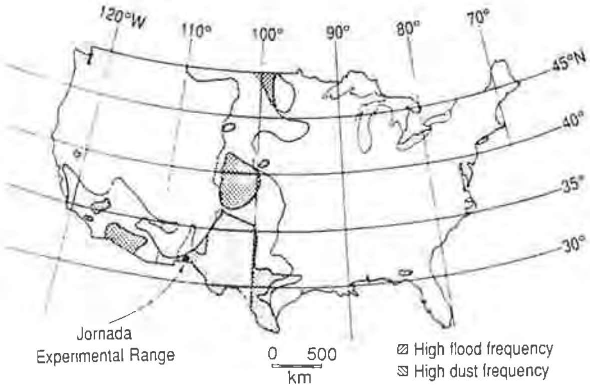

Fig. 4. Areas of the United States with a flash flood index in excess of 0.5 for a 20-year period and an annual frequency of dust hours, when visibility is <11 km, in excess of 0.4% (*107*).

the observations of Breman and de Wit (*42*) that nomadic livestock systems are well adjusted to the ecosystems of the southern Sahel. The impact of nomadic herders and the harvest of plant resources are spread evenly and at low levels across the landscape (*101*). When people and livestock are concentrated into small areas in which their impact leads to an increased heterogeneity of soil resources, permanent degradation of the productive capacity of the land occurs (*6*). Satellite images show that the distribution of arid land with low productivity has expanded in southern New Mexico and the Sahel (*102*). Particularly in the Sahel, human population is increasing rapidly (*9*); however, desertification of these areas is also probable if global climate change is occuring (*8*).

Currently, arid lands cover about 12% of the earth's land surface (*63*). Semiarid grasslands and woodlands occupy an even larger area, so the total extent of dryland ecosystems is about one-third of the earth's land surface (*103*). Although these lands contribute little to the net primary productivity of the biosphere (*104*), they affect a number of global conditions through abiotic processes. Arid lands are likely to play a greater role in global biogeochemical function in the future. The area of arid land is expected to increase, along with episodic, long-range transport of soil resources. These changes may affect regions that are far removed from arid lands and possibly conditions of the entire planet.

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106. The volatilization of NH_3 from covered, in situ soil cores (10 cm in diameter) was collected by absorption in 10 ml of 2% H_2SO_4 for a 24-hour period, followed by analysis for NH_4 with a Technicon Autoanalyzer. Rainfall was simulated by additions of water to bring the soil core to field capacity in a depth of 0 to 15 cm. For each storm between October 1987 and May 1989, rainfall was collected on the Jornada Experimental Range with an Aerochem Metrics Collector and analyzed for NH_4 with Technicon Autoanalyzer methods.
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Presentations made at Scientific Meetings and Workshops as part of the Jornada LTER-III

15 October 1994-- present

International Symposium and Workshop on Desertification in Developed Countries, Tucson, Arizona, 24-29 October 1994

Keynote Address by W.H. Schlesinger, "Long-Term Ecological Research in the United States."

Poster by Al Peters, "Derivation and Temporal Analysis of Satellite-Based Vegetation Indices in Desert Shrub Communities of the Arid Southwest."

Contributed paper by H.C. Monger, "A Major Desertification Episode beginning about 8,000 years ago in the Chihuahuan Desert of southern New Mexico and western Texas."

International Workshop: Japan-U.S. Global Change Research, The National Insitute of Japanese Environmental Studies, Honolulu, Hawaii, October 25-28, 1994

Invited paper by J.F. Reynolds, entitled "Desertification in the southwestern U.S.: Patterns, processes and current modeling efforts."

Eighth Mogollon Archaeology Conference, El Paso, Texas, 21-22 October 1994.

Contributed papers by H.C. Monger, "Eolian geomorphology, survey intensity, and landscape patterning in the surface archaeological record," and

"Eolian geomorphology, artifact patterning, and assemblage composition."

Annual Meeting of the Geological Society of America, Seattle, 24-27 October 1994

Contributed Paper by S.L. Connin, R.A. Virginia, and C.P. Chamberlain. "Recent pedogenic carbonate formation in the southwestern United States from carbon isotope measurements."

Annual Meeting of the Soil Science Society of America, Seattle, November 1994

Symposium Paper by H.C. Monger. "Stable carbon and oxygen isotopes of carbonates as paleoenvironmental indicators in arid regions."

Annual Meeting for the Society of Range Management. Symposium on Alien Plant Invasions, Phoenix, Arizona, 17 January 1995

Symposium Paper by L.F. Huenneke, "Ecological Impacts of Plant Invasions in Rangeland Ecosystems."

Fifth Annual Jet Propulsion Laboratory Airborne Earth Science Workshop, Pasadena, California, 23-26 January 1995

Workshop Paper by H.B. Musick et al., "Use of AIRSAR to identify wood shrub invasion and other indicators of desertification in the Jornada LTER."

Annual Meeting of the Soil Ecology Society of America. Fort Collins, Colorado, March 1995

Contributed paper by B.S. Bamforth, D.W. Freckman, and R.A. Virginia. "Early soil biogenesis."

Fourth Annual Professional Range Managers Forum, Brownwood, Texas, March 1995

Invited Symposium Paper by K.M. Havstad, "Long-term ecological monitoring technologies."

International Symposium for IGBP-GCTE, Tahoe City, California, May 14-18, 1995

Invited talk by J.F. Reynolds, entitled "Climate variability as a stressor in arid environments."

Ninth Annual Wildland Shrub Symposium, Las Cruces, N.M., May 23-25, 1995

Plenary Paper by K.M. Havstad. "Reflections from nearly a century of rangeland research in the Jornada basin."

Plenary Paper by W.H. Schlesinger, "Understanding global desertification processes through long-term ecological research in the Jornada basin."

Contributed Paper by L.F. Huenneke, "Shrublands and grasslands of the Jornada Long-Term Ecological Research site: Desertification and plant community structure in the northern Chihuahuan desert."

Contributed Paper by H.C. Monger, et al. "Vegetation dynamics during the late Quaternary in the northern Chihuahuan desert based on stable isotopes in pedogenic carbonates."

Poster by R.E. Estell, et al. "Tarbush leaf surface terpene profile in relation to mammalian herbivory."

Poster by D.C. Lightfoot, " A comparison of grasshopper species composition and population dynamics in northern Chihuahuan desert grassland and shrubland communities."

Contributed Paper by W.G. Whitford, "Morphological variation in creosotebush, *Larrea tridentata*, affects ecosystem processes."

Contributed Paper by A.E. Hartley, "Nitrogen trace gas emission from grassland and shrubland soils in the Jornada Basin."

Contributed Paper by V.P. Gutschick, et al. "Physiological control of evapotranspiration by shrubs: Scaling measurements from leaf to stand with the aid of comprehensive models."

Contributed Paper by A.G. de Soyza, et al. "Effects of summer drought on the water relations, physiology, and growth of large and small plants of *Prosopis glandulosa* and *Larrea tridentata*."

Contributed Paper by Sean L. Connin, et al. "Origin and flux of soil carbon following shrub invasion in the Chihuahuan desert: Isotopic analysis of community change."

Contributed Paper by J. Thompson and L.F. Huenneke. "Regneration niches and differential germination in shrub-land perennials."

Contributed paper by David Mouat et al. "Time-series of satellite data to identify mesquite response to stress as an indicator of ecosystem health"

Contributed paper by Barry Middleton and A. Peters. "Monitoring arid and semi-arid shrubs and grassland communities using coarse resolution satellite data."

Contributed Paper by R.A. Virginia, "Experimental studies of shrub resource islands: Are they the key to the stability of aridlands?"

Contributed Paper by J.F. Reynolds, "Modeling desertification: The importance of shrub resource islands."

World Conference on Natural Resource Modelling, University of Natal, Pietermaritzburg, South Africa, July 5-10, 1995.

Invited Plenary Paper by J.F. Reynolds, entitled "Desertification in the southwestern U.S.: A model system for developing a general patch arid lands simulator."

International Workshop: Resource Analysis for South Africa, Itala Game Reserve, South Africa, July 10-16, 1995.

Invited paper by J.F. Reynolds, entitled "Can we scale patch processes to predict landscape dynamics in arid ecosystems?"

Annual Meeting of the Ecological Society of America, August 1995, Snowbird, Utah.

Contributed paper by L.F. Huenneke et al., "Plant biodiversity and ecosystem function in the northern Chihuahuan desert."

Contributed poster by H. Bassirirad, "Differential nutrient uptake responses to CO_2 enrichment in three desert species."

Contributed poster by V. Gutschick, C. Maxwell, E. Jackson N. Stotz, F. Najera and C. Rivera-Figueroa, "Stomatal conductance responses to humidity and water stress in three biomes."

International Humic Substances Society, Atlanta, Georgia, 27-31 August 1995

Invited Paper by H.C. Monger, entitled, "Carbon in desert soils: Its nature and isotopic significance."

International UNEP Workshop on Combatting Global Warming by Combatting Land Degradation, Nairobi, Kenya, 4-8 September 1995

Invited paper by Sean Connin, entitled, "The carbon budget of drylands."

Workshop for the South-Central Section of the National Initiative for Global Environmental Change (NIGEC), U.S. Department of Energy, New Orleans, Louisiana, 12-13 October, 1995

Contributed paper by V. Gutschick, entitled, "Predicting large scale patterns in vegetated-surface conductance for CO_2 and water vapor: Physiological and ecological regularities, and consequences."

Western Society of Weed Science, Albuquerque, New Mexico, 14 March 1996

Symposium paper by L.F. Huenneke, entitled "Ecological impacts of invasive plants in natural resource areas."

Invited plenary paper by K.M. Havstad, entitled "Linking Rangeland Science to Western Rangeland Issues."

Twenty-First Annual Meeting and Symposium of the Desert Tortoise Council, Las Vegas, Nevada, March 29-April 1, 1996

Invited paper by William H. Schlesinger and J.F. Reynolds, entitled, "Global Change and Desert Ecosystems."

Invited paper by William H. Schlesinger, J.A. Raikes, A.E. Hartley, and A.F. Cross, entitled, "On the spatial pattern of soil nutrients in desert ecosystems."

Annual Meeting of the Association of American Geographers, Charlotte, North Carolina, April 1996

Contributed Paper by Mel Neave, entitled "Impact of animal disturbance on discharges and sediment yields on a semiarid piedmont surface in southern New Mexico."

XV Congreso Argentino de la Ciencia del Suelos, Santa Rosa, Argentina, May 1996

Invited paper by H.C. Monger and D.R. Cole, entitled "Comparacion de isotopos en calcretes en los E.U.A. y Argentina."

1996 Annual Conference, Society for Ecological Restoration, New Brunswick, New Jersey, June 17-22, 1996

Contributed paper by E.L. Fredrickson, J.E. Herrick K.M. Havstad and J. Winder, entitled "Working together to restore desert rangelands."

Annual Meeting of the Ecological Society of America, Providence, Rhode Island, August 9-12, 1996

Contributed poster by L.F. Huenneke, entitled "Temporal patterns of primary productivity in Chihuahuan Desert ecosystems of the Jornada LTER site."

Contributed poster by R.A. Virginia, M. Ho and J. Reynolds, entitled "The stability of desert shrub resource islands following disturbance."

Contributed poster by J.F. Reynolds, R.A. Virginia, P.R. Kemp A.G. DeSoyza and D.C. Tremmel, entitled "The effect of seasonal drought on the stability of desert shrub resource islands."

Contributed paper by Roberto J. Fernandez and James F. Reynolds, entitled "Does the xerophytism vs. palatability hypotheses explain historic grass decline in the northern Chihuahuan desert?"

Contributed paper by S.L. Connin, R.A. Virginia, L.F. Huenneke, K. Harrison and W.H. Schlesinger, entitled "Changes in ecosystem carbon storage following shrub invasion in the Jornada Basin, New Mexico."

Contributed paper by Jayne Belnap, F. Pichel-Garcia and Dale Gillette, entitled "Microstructure of semi-arid cyanobacterial-lichen soil crusts and their susceptibility to wind erosion."

Contributed paper by V.P. Gutschick, C.J. Maxwell, M. Montes-Helu, C. Rivera-Rigueroa, E.C. Jackson, F.T. Najera, J. Anchondo, D. Reta-Sanchez, F. Popiel and B.J. Choudhury, entitled "How well can we scale evapotranspiration from leaf to km level on a semi-arid landscape."

Contributed paper by Ho, M., R.A. Virginia, and D.W. Freckman, entitled "Soil spatial variation along a toposequence in Taylor Valley, Antarctica."

Fifth International Conference on Desert Development, Lubbock, Texas, August 12-17, 1996

Contributed paper presented by A.M. Pilmanis and W.H. Schlesinger, entitled "Spatial assessment of desertification of vegetation pattern and available soil nitrogen."

Contributed paper by H.C. Monger, entitled "Natural cycles of desertification in the Chihuahuan desert of North America."

88th Annual Meeting of the Soil Science Society of America, Indianapolis, Indiana, November 3-8, 1996

Invited symposium paper by W.H. Schlesinger et al., entitled "Plant Soil Interactions in Deserts."

Contributed symposium paper by H.C. Monger et al., entitled "Objectives, history, and future plans for the Desert Soil-Geomorphology Project."

12 Annual Symposium, International Association of Landscape Ecology, Durham, N.C., March 13-15, 1997

Contributed paper by Habin Li and J.F. Reynolds, entitled "Desert Landscape Dynamics as Combined Markov and Cellular Automaton Processes: Models and Applications."

Annual Meeting of the Association of American Geographers, Fort Worth, Texas, April 1-6, 1997

Contributed paper by Melissa Neave, entitled "Considering the geomorphic implications of small mammal activities on rangeland degradation in the Jornada Basin, southern New Mexico."

Contributed paper by David Howes and Athol D. Abrahams, entitled "Modling runoff in a desert shrubland ecosystem."

International Symposium and Workshop on "Combatting Desertification," Tucson, Arizona, May 12-16, 1997

Contributed paper by James F. Reynolds and Ross A. Virginia entitled, "Modeling desertification: The importance of shrub resource islands."

Contributed paper by Jayne Belnap, F. Pichel-Garcia and Dale Gillette, entitled "Microstructure of semi-arid cyanobacterial-lichen soil crusts and their susceptibility to wind erosion."

Invited paper by E. Fredrickson, K. Havstad and R. Estell entitled, "Perspectives on Desertification: Southwestern United States."

Contributed poster by H.C. Monger, L.F. Huenneke, and K.M. Havstad, entitled "Geomorphic-vegetation relationships in the Jornada Basin, southern New Mexico."

International Workshop on Dissipation of N from the Human Nitrogen Cycle, and its Role in Present and Future N_2O Emissions to the Atmosphere, Oslo, Norway, May 22-25, 1997

Contributed poster by Anne E. Hartley and W.H. Schlesinger, entitled, "Environmental Controls on Nitrogen Cycling in Northern Chihuahuan Desert Soils."

Workshop on the Changing Water Regimes in Drylands, Lake Tahoe, California, June 9-13, 1997

Invited, plenary paper by James F. Reynolds, entitled "Modelling Vegetation Responses."

Annual Meeting of the Ecological Society of America, Albuquerque, N.M., August 11-14, 1997

Contributed paper by W.H. Schlesinger and A.D. Abrahams, entitled "Runoff losses of nitrogen and phosphorus from grassland and shrubland plots in the Chihuahuan desert of New Mexico."

Contributed poster by J.F. Reynolds et al., entitled "The Patch Dynamics Arid Lands Simulator (PALS): I. Predicting the role of climate change and disturbance on rates of desertification."

Contributed poster by R.A. Virginia et al., entitled "The Patch Arid Lands Simulator (PALS): II. Predicting the effects of drought on above- and belowground litter decomposition and nitrogen cycling."

Contributed poster by Paul R. Kemp et al., entitled "The Patch Arid Lands Simulator (PALS): III. Predicting the effects of variation in rainfall and disturbance on soil water dynamics in the Chihuahuan desert."

Contributed paper by Roberto Fernandez and J.F. Reynolds, entitled "Drought, grass functional diversity, and grazers' selectivity: A supply-side model."

Contributed paper by R.P. Herman, entitled "Shrub invasion and bacterial community pattern in a Swedish pasture soil."

Contributed paper by J.E. Baggs and L.F. Huenneke, entitled "The influence of *Bouteloua eriopoda* on the community structure of a semi-arid grassland."

Contributed poster by H.E. Miller et al., entitled "Plant-community response to manipulations of biodiversity."

Contributed paper by A.M. Pilmanis and W.H. Schlesinger, entitled, "Changes in spatial patterns of soil resources and vegetation across a desertification gradient in the Chihuahuan desert of New Mexico."

Contributed paper by R.E. Miller and L.F. Huenneke, entitled "Demographic variation within a population of *Larrea tridentata.* creosotebush."

Contributed paper by M.S. Zeisset and L.F. Huenneke, entitled, "Effects of vegetation community structure on insect community structure in the Chihuahuan desert."

Invited symposium presentation by L.F. Huenneke, entitled "No species is an island: Interactions between plant invasions and other aspects of global change."

Rangeland Desertification International Workshop, Reykjavik, Iceland, 16-19 September 1997

Invited paper by K.M. Havstad and W.H. Schlesinger entitled "Rangelands and Nutrients"

In addition to the presentations made at these scientific meetings, each summer the Jornada LTER holds its own, informal research symposium, known as "The Friends of the Jornada." The program for this year's symposium, held last week, follows this page.

SEVENTH ANNUAL FRIENDS OF THE JORNADA SYMPOSIUM

Sponsored by USDA/ARS Jornada Experimental Range and the Jornada Long-Term Ecological Research Site
Thursday, July 10, 1997
Guthrie Hall, Room 100

8:30 AM Welcome and Introductions - Kris Havstad, USDA-ARS-Jornada Experimental Range and Bill Schlesinger, Duke University and Jornada LTER PI

Morning Moderator: Jeff Herrick, USDA-ARS-Jornada Experimental Range

8:45 AM	L.F. Huenneke, NMSU, Biology Dept. - *Plant community structure in Jornada ecosystems*
9:00 AM	R.A. Virginia and J.F. Reynolds, Dartmouth College and Duke University - *Impacts of simulated drought on shrub resource islands*
9:15 AM	S. Connin, The Sonoran Desert Laboratory - *Formation of desert grasslands in the southwest from isotopic study of fossil herbivores*
9:30 AM	L.E. Hipps, K. Ramalingam, W. Kustas, and J. Prueger, Utah State University and USDA-ARS - *Energy balance and spatial structure of vegetation in grass and mesquite regions*
9:45 AM	J.R. Barrow, USDA-ARS-Jornada Experimental Range - *A developing perspective on resource conservation and distribution in an arid environment*
10:00 AM	BREAK (refreshments provided)
10:30 AM	J. Belnap, USGS - *Effect of disturbance on soil resources*
10:45 AM	P. Herman, NMSU, Biology Dept. - *Shrub islands and microbe distribution- comparing the Jornada with a Swedish pasture*
11:00 AM	J. Reynolds, Duke University, Botany Dept. - *Patch and landscape models of the Jornada*
11:15 AM	D. Brown, Eastern New Mexico University, Biology Dept. - *Intraspecific variation in honey mesquite seedling growth in response to CO_2 enrichment*
11:30 AM	Karen Humes, University of Oklahoma - *Mapping vegetation and surface energy fluxes with remotely sensed data*
11:45 AM	D. Gillette, Natl. Ocean. Atmosph. Admin. - *Threshold friction velocities for wind erosion at the Jornada Experimental Range*

12:00 PM LUNCH (on own)

Afternoon Moderator: Ed Fredrickson, USDA-ARS-Jornada Experimental Range

1:30 PM	D.M. Anderson, USDA-ARS-Jornada Experimental Range - *Fluorescence, forage and the future for botanical composition*
1:45 PM	J. Holechek, R. Valdez, and J. Joseph, NMSU, Animal and Range Sciences - *Stocking rate influences on wildlife populations in the Chihuahuan Desert*
2:00 PM	D.T. Kirkpatrick, Human Systems Research - *Tularosa Basin ecosystem database*
2:15 PM	H.C. Monger and R.A. Gallegos, NMSU, Agronomy and Horticulture - *Soils and quaternary landscape evolution, Jornada Basin*
2:30 PM	D.A. Howes, State Univ. Of NY at Buffalo, Geography Dept. - *Modeling runoff in a desert shrubland ecosystem*
2:45 PM	BREAK (refreshments provided)
3:00 PM	P.W. Hyder, NMSU, Jornada Experimental Range - *The Chihuahuan Desert Nature Park - A window on the desert*
3:15 PM	V. Gutschick, NMSU, Biology Dept. - *Image processing to identify plant species in aerial photos*
3:30 PM	A.R. Johnson, NMSU, Jornada Experimental Range - *Vegetation classification and assessment using AVHRR imagery*
3:45 PM	D.L. Johnson, University of Illinois - *Aspects of soil and landform evolution, McGregor Range, southcentral New Mexico*
4:00 PM	R.J. Fernandez, Duke University, Botany Dept. - *Potential growth vs. drought resistance among the warm season grasses of the Jornada*

5:30-7:00 PM Social at Jornada Range Headquarters (map to Jornada on back)

7:00-9:00 PM Dinner

***Posters on display all day in the hallway of Guthrie Room 100** (listed on back)*

Students Trained as part of the Jornada LTER-III

15 October 1994 -- present

Completed Degree Requirements:

Graduate:

Tiszler, J. 1994. Changes in soil nitrogen dynamics with the establishment of desert shrubs in a Chihuahuan black grama grassland. M.S. Thesis, San Diego State University (R.A. Virginia, advisor).

Brisson, J. 1994. Growth plasticity and neighborhood interactions with special reference to creosotebush (Larrea tridentata). Ph.D. Dissertation, San Diego State University (J.F. Reynolds, advisor)

Horton, J.D. 1995. Using kriging to predict distribution of arid vegetation, with discussion of cokriging field data and satellite imagery. Ph.D. Dissertation, New Mexico State University (K.M. Havstad, advisor).

Thompson, J.B. 1995. Regeneration niches and nurse plant associations in Chihuahuan desert perennials. M.S. Thesis, New Mexico State University (L.F. Huenneke, advisor).

Marlies, E.H. 1995. Application of stable carbon and nitrogen isotopic signatures as tracers of vegetation changes accompanying desertification. M.S. Thesis, Dartmouth College (Ross A. Virginia, advisor).

Encina-Rojas, A.E. 1995. Detailed soil survey of the Jornada LTER (Long-term Ecological Research) Transect vicinity, southern New Mexico. M.S. Thesis, New Mexico State University (H. Curtis Monger, advisor).

Buck, Brenda. 1996. Late Quaternary landscape evolution, paleoclimate, and geoarchaeology, southern New Mexico and west Texas. Ph.D. Dissertation, New Mexico State University (H. Curtis Monger, advisor).

Pan, J.J. 1996. The effects of grazing history, plant size, and plant density on growth and production of black grama grass (Bouteloua eriopoda). M.S. Thesis, New Mexico State University (M. Cain, advisor).

Li, Gang. 1996. Sediment transport capacity of laminar overland flow. Ph.D. Dissertation, State University of New York, Buffalo (A. Abrahams, advisor).

Connin, Sean L. 1996. Variations in the isotopic composition of pedogenic carbonte: contributions of vegetation, soil disturbance and diagenesis. Ph.D. Dissertation, Dartmouth College (R.A. Virginia, advisor).

Lassetter, W.L. Jr. 1996. Changes in soil labile-C indicated by the ratio of microbial biomass-C to total organic-C in a semiarid grassland undergoing desertification. Ph.D. Dissertation, University of Nevada, Reno (R.A. Wharton, Jr., advisor).

Hartley, A.E. 1997. Environmental controls on nitrogen cycling in northern Chihuahuan desert soils. Ph.D. Dissertation, Duke University (W.H. Schlesinger, advisor).

Undergraduate:

Bortz, Heavin. 1996. B.S. Duke University (1996 REU at Jornada).

Garcia, Antoni. 1995. B.S. New Mexico State University (1994 REU at Jornada).

Gross, Kevin. 1996. A.B. Duke University (1995 REU at Jornada).

Gurrola, Javier. 1995. B.S. New Mexico State University (1994 REU at Jornada)

Lacy, Colleen. 1996. B.S. New Mexico State University (1994 REU at Jornada)

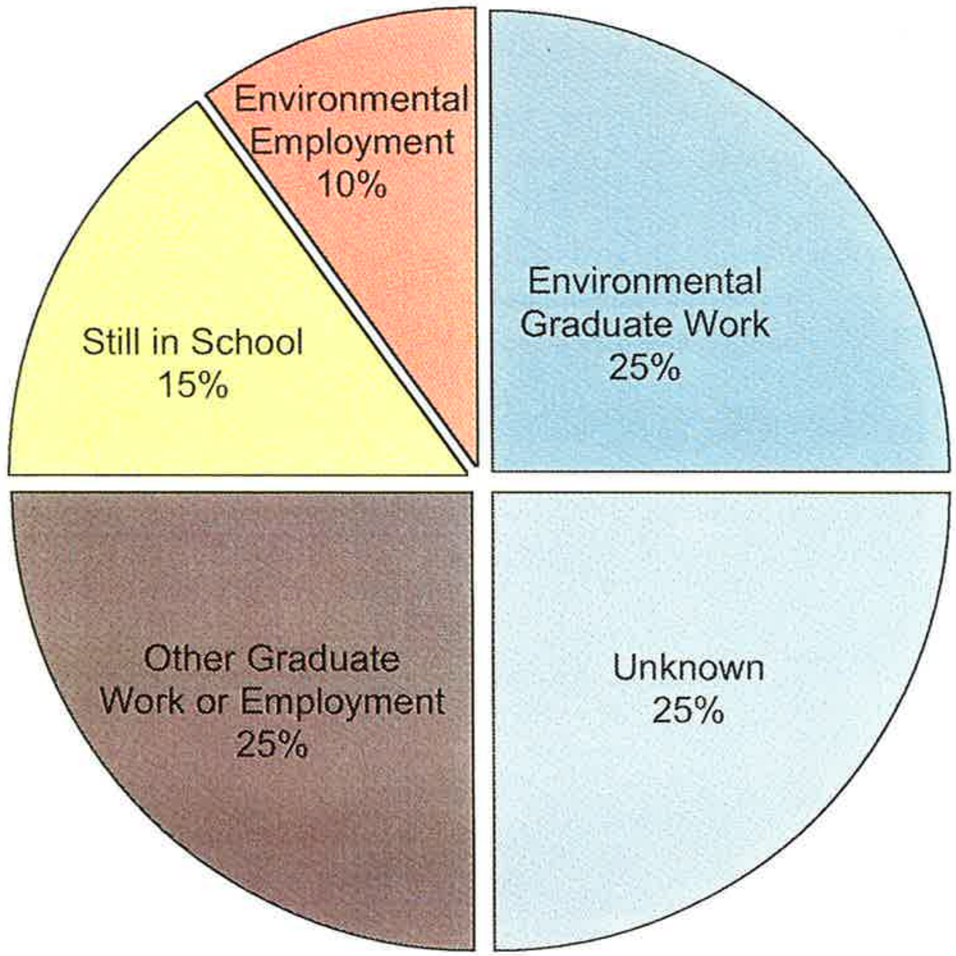
Middleton, Barry. 1995. B.S. New Mexico State University (1994 REU at Jornada).

Provencio, Kerri. 1997. B.A. George Mason University (1994 REU at Jornada)

Rayburg, Scott. 1996. B.A. State University of New York at Buffalo (1996 REU at Jornada).

Wright, Allison. 1997. B.S. Eastern Michigan State University (1994 REU at Jornada).

REU Students of the Jornada (1991-1996)



In Progress:

Alexander, Anthony. M.S. Program, New Mexico State University (R.P. Herman, advisor)

Ambro, Sharon. B.A. Program, Marietta College, Ohio (1997 REU Student, Peter Herman, advisor).

Amweg, Erin. B.S. Program, Duke University. (1997 REU Student, W.H. Schlesinger, advisor)

Baggs, J. M.S. Program, New Mexico State University (L.F. Huenneke, advisor).

Bogner, Heidi. B.S. Program, New Mexico State University (1997 REU Student, L.F. Huenneke, advisor)

Core, Lisa. A.B. Program, Dartmouth College (1997 REU Student, R.A. Virginia, advisor)

Fernandez, R. Ph.D. Program, Duke University (J.F. Reynolds, advisor).

Gallegos, R. M.S. Program, New Mexico State University (H.C. Monger, advisor)

Granados, A. Ph.D. Program, New Mexico State University (H.C. Monger, advisor)

Haydu, Carrie Ann., M.S. Program, New Mexico State University (H.C. Monger, advisor).

Herrera-Matos J. M.S. Program, New Mexico State University (R.P. Herman, advisor)

Howes, David. Ph.D. Program, State University of New York at Buffalo (A.D. Abrahams, advisor)

Kipp, J.M. Ph.D. Program, New Mexico State University. (H.C. Monger, advisor).

Langley, Adam. B.S. Program, North Carolina State University (1997 REU Student, Peter Herman, advisor)

Love, Nicole. B.A. Program, State University of New York, Buffalo. (1997 REU Student, A.D. Abrahams, advisor).

Martinez-Rios, J. Ph.D. Program. New Mexico State University. (H.C. Monger, advisor).

McCabe, S. M.S. Program. State University of New York, Buffalo. (A.D. Abrahams, advisor [also 1995 REU student])

Miller, Heather. Ph.D. Program. New Mexico State University (L.F. Huenneke, advisor).

Mooney, J. B.A. Program. Dartmouth College. (1995 REU Student, R.A. Virginia, advisor).

Najera, F. B.S. Program. New Mexico State University. (1994 REU Student, V.P. Gutschick, advisor).

Neave, M. Ph.D. Program, State University of New York, Buffalo. (A.D. Abrahams, advisor)

Pilmanis, A. Ph.D. Program, Duke University. (W.H. Schlesinger, advisor).

Robison, Rondi. B.S. Program, University of Guelph, Ontario. (1997 REU Student, L.F. Huenneke, advisor).

Rucker, Amber. B.S. Program, Southwestern College, Kansas (1997 REU Student, L.F. Huenneke, advisor).

Ziesset, Michelle, M.S. Program, New Mexico State University (L.F. Huenneke, advisor)

K-12 EDUCATIONAL ACTIVITIES:

USDA and LTER personnel have developed an educational program for K- 12 students and their teachers in the Las Cruces, NM, Anthony, NM-TX, and El Paso, TX, areas. Field trips for approximately 500 students in groups of 10-50 have been a core part of this program. Students visit science stations devoted to animal ecology, plant chemistry, photosynthesis, animal agriculture, animal ecology, soil morphology, and invertebrate ecology. All stations involve hands on experiences and, in some cases, filed measurements of selected biological properties. We have complemented this program with classroom demonstrations and laboratory visits to facilities at New Mexico State University. We have worked with over 1500 students in these programs during the current fiscal year.

In addition, we have initiated a First Step program (funded by NSF to the Agricultural Research Service), where local grade school science teachers spend a month working on science projects for their classroom that relate to the research conducted on desert ecology in the Jornada Basin. The emphasis is on developing affordable projects that elementary students can do in their classrooms over a semester. Four teachers were involved in the First Step Program in FY97.

The Jornada has also established a liaison committee of individuals representing various interests of desert ecology, rangeland resources, and animal agriculture. This ten person committee has representation from the federal stewardship agencies, environmental organizations, and livestock advocacy groups. The committee meets twice each year, and current and future research activities at the Jornada are discussed. This joint activity involves the USDA/ARS Jornada Experimental Range with cooperating researchers.

Articles in the popular press, television interviews, and other public media that interpret Jornada LTER research for a general audience. (See also K through 12 Education activities under tab "Students/Education")

October 15, 1994 -- present

Publications:

"Science at Home on the Range," November 1994 article in *Agricultural Research*, a monthly magazine published by the by the U.S.Department of Agriculture for farmers and ranchers.

"Watching Desert Creep," December 1994 article in *Dialogue,* a weekly newspaper published for the Duke University community.

"Students Study Growth in NM," December, 12, 1994 article in *The El Paso Times.*

"How to Make a Desert," February 1995 article in *Discover*, a national monthly science magazine published by The Walt Disney Company.

"Success Secrets of Desert Plants," March 1995 article in *Agricultural Research* (see above).

"Desert Holds Keys to Land, People who live on land," October 19, 1995 article in the *Las Cruces Sun Times.*

Presentations

Laura Huenneke spoke on "Ecological Impacts of Grazing in Semi-arid Rangelands" -- the first of four lectures in a symposium on public land grazing in the Southwest, "What's the Beef?" held at the Southwest Environmental Center, Las Cruces, NM, October 1996.

Kris Havstad briefed the staff of the Smithsonian Natural History Museum in support of their development of a new exhibit entitled "Forces of Change," and he described the value of the long-term datasets gathered at the Jornada. February 1997.

Workshops

"Ecologically Sensitive Ranching," organized by Kris Havstad and Jim Winder, Santa Fe, New Mexico, June 1997

Video

"Evolution of the Rio Grande Valley," a 30-minute video prepared for distribution to high school and early college students describing the recent geomorphological history of the Jornada Basin.

The article in *Discover* is an especially readable description of our research program, and a reprint is included herewith.

REVERSING TIME

Discover

THE WORLD OF SCIENCE

FEBRUARY 1995

BEAST IN THE BELLY

A STRANGE TALE OF MEDICINE AND FAITH

By Dr. Sherwin Nuland

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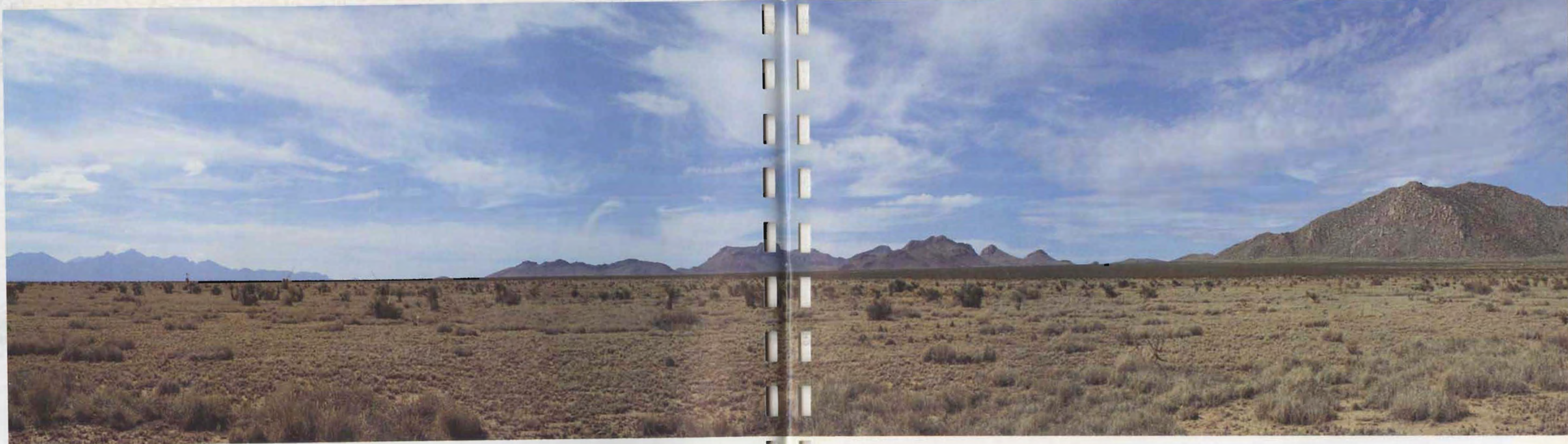


how to make a desert

You don't need to destroy all the plant life you see—just rearrange it a little. Then let nature do the rest.

BY CARL ZIMMER

Photographs by David Hamilton

AT TIMES THE DESERT CAN MAKE PEOPLE SEEM SMALL AND INCONSEQUENTIAL and even foolish. Bill Schlesinger feels that way today. With spikes and tape measure, he and co-worker Jane Raikes have staked out some 100 square yards of desert land in the Jornada Basin, 15 miles north of Las Cruces, New Mexico. Their claim includes some low-slung olive-drab creosote bushes, a clump of wispy tan snakeweed, and a lot of bare soil. Some ants roam the ground. A palm-size Texas horned lizard tries to stay cool in the shade of a creosote. It is a patch of desert that looks pretty much like countless other patches of desert in North America. ▪ Why anyone—even someone like Schlesinger, a biogeochemist from Duke University in North Carolina—should bother to mark and study this particular patch of desert is hard for an outsider to divine. Schlesinger is aware of this. So, as he calls out pairs of numbers to Raikes, he is not surprised by the puzzled looks he gets from passing weekend horseback riders. Raikes goes to the corresponding coordinates in the plot, armed with a rock hammer and a metal pipe. She drives the pipe two inches into the ground, the blows ringing out in the silence. Then she pries the pipe out and taps the clogged soil into a Ziploc bag. "I can see it in the press now," says Schlesinger. " 'They banged a pipe in the dirt many times and found it exciting.' "

Despite his habitual self-mockery, Schlesinger knows that the tablespoons of soil he and Raikes are collecting may help reveal a profound secret of the desert. If Raikes and Schlesinger had come to this spot 150 years ago, they would have been surrounded by almost uninterrupted grasslands stretching across the basin. Somehow the Jornada has since changed, and Schlesinger, Raikes, and the other researchers who work here think they know why. In many cases, they believe, a desert is like a living organism. Like a cactus or a sidewinder, it needs parents to give it birth, but once kicked into the world it can grow and thrive on its own. Deserts aren't necessarily the product of outside forces like decreasing rainfall, they say. Rather, it's the internal ecology of the desert itself—its web of plants, animals, and soil—that drives its growth to maturity and stability. Nor does the transformation of a grassland to a desert necessarily mean the creation of a place where life is more scarce—only one where life is rearranged.

By the turn of the century people had begun to notice that the Jornada was changing. The grass was thinning, and the mesquite and creosote spreading. The ground became bare; in some places low dunes formed. Ranching was becoming less and less profitable.

Grasslands are changing into full-blown deserts not only in the Jornada Basin but around the world, on every continent but Antarctica—on every continent, that is, where humans have settled. In North America alone an estimated 1.1 billion acres have been desertified, and researchers suggest that global warming may generate more desert acreage in the coming century. Desertification is sufficiently serious a threat that representatives of 87 countries have drafted a treaty to combat it; only two other environmental crises—ozone destruction and global warming—have earned such attention. But scientists still argue about exactly how desertification happens, how much of it is a matter of natural fluctuations, and how much is man-made. The political impact of the debate is huge—witness the conflict between ranchers and Interior Secretary Bruce Babbitt over grazing rights on public land. If the model Schlesinger and his colleagues at the Jornada have built proves true, it will inject some desperately needed science into this debate.

There's a touch of ecological hubris in trying to generalize to the entire globe from the Jornada's 310 square miles, but then, the Jornada is an exceptional place. It is arguably the best-studied desert in the world. As Kris Havstad, the director of the U.S. Department of Agriculture's Jornada Experimental Range, drives around on a tour of the basin with Schlesinger and Raikes, he recounts the Jornada's long history: "As early as 1600, Spanish wagons were traveling from Mexico City to Santa Fe with livestock. They tried to avoid the Rio Grande because the terrain was broken and heavy and they'd get bogged down. So they crossed over the mountains, up into the plains. The problem is, there's almost no water here. You read the journals people kept of their trip, and when they get here, they get really quiet."

The 90-mile trail was soon given the name Jornada del Muerto—Journey of the Dead. Dry as it was, though, the basin was not a desert at the time.

"Nothing could exceed the beauty of the country we traveled over this morning," wrote May Humphrey Stacy after crossing the basin in 1857. "The whole extent, as far as vision reached ahead, was a level plain, covered thickly with the most luxurious grass."

The Jornada Basin is at the northern edge of the Chihuahuan Desert, which runs south 1,000 miles from New Mexico, through the western wedge of Texas and down the backbone of Mexico. Creosote bushes and small, spiny mesquite trees dominate the landscape. Yet for thousands of years the Jornada had been a stable grassland. The closely packed tufts of golden-stalked black grama grass attracted Mexican cattle raisers, and after them, Americans.

But because those early settlers could water their livestock only at springs in the bordering mountains, they raised rather few cattle. "It wasn't until we brought the technology to drill wells in places like this, where the water is 400 feet down, that this land opened up to heavy grazing," says Havstad. "After water was brought to the surface in the 1880s, there were 20,000 head of cattle out here. This place just got hammered."

By the turn of the century people had begun to notice that the Jornada was changing. The grass was thinning, and the mesquite and creosote were spreading. The ground became bare; in some places low dunes formed. Ranching was becoming less and less profitable. Similar changes were happening throughout the American West, and in 1912 USDA officials fenced off 192,000 acres of the basin and set up the Experimental Range, where they tried to understand what was happening and how they could stop it.

As Havstad tells the tale of the Jornada, he is looking out the truck window for some of that history. Half a mile down the road he finds a red ribbon tied to a barbed-wire fence; 50 yards from the road is another ribbon tied to one of the spear-shaped leaves that explode from the top of a soap-tree yucca. Nearby, four rusted steel posts sprout from the ground, forming the corners of a square. When the USDA took over the Jornada 83 years ago, it sent surveyors to stake out 104 such sites, and for decades thereafter USDA researchers faithfully sketched the vegetation in each square. Havstad has some of the early drawings of this plot in hand. They show scattered patches of grass. Now the four posts enclose only mesquite.

These early researchers did not consider themselves ecologists. They were range scientists, dedicated to figuring out how to make the Jornada grow food for cattle. They did everything they could to stop the basin's transformation. They cut the herd down to a few hundred head. They tore up mesquite, poisoned the shrubs, seeded grasses, and dug giant pits to help water penetrate the ground. They failed. The Jornada researchers estimate that in 1858 about 5 percent of the range was dominated by mesquite or creosote, 37 percent had a few shrubs in it, and the remaining 58 percent was shrub free. Just over 100 years later, in 1963, 64 percent of the range was dominated by mesquite and creosote and none of the remaining 36 percent could unqualifiedly be called grassland any longer. Now, Havstad estimates, about 80 percent is classic desert shrub land.

Research suggests that, once introduced, shrubby plants like mesquite trees—which have spread across the Southwest—can change a semiarid grassland into desert.

Heartbreaking as the desertification was to range scientists, it made the Jornada a fascinating place for desert ecologists. "You can find virtually every kind of vegetation unit there that you would find anywhere in the Chihuahuan Desert," says Walt Whitford. Whitford began studying the Jornada in 1964 when he came to New Mexico State University in Las Cruces. The short drive from campus and long history of research made it an attractive place for doing ecology. And most important, says Whitford, he could really *do* ecology there. "You can go to national parks, but you can't do experiments in them. The Jornada is a huge piece of land dedicated to research. We can move livestock, impose droughts, burn strips—we can do almost anything you can imagine."

In 1981 Whitford launched the Jornada Long-Term Ecological Research Project. His own expertise was in desert animals, and he enticed other researchers to join him to study the Jornada's plants, its soil chemistry, its patterns of wind and water. But by the mid-eighties, as the data crammed their filing cabinets and computers, Whitford's team began to feel more like bookkeepers than scientists. "The big problem was to relate what we were doing at a single site in New Mexico to global desertification," explains Duke ecologist James Reynolds. Precisely how had the Jornada changed, they asked, and was the same process responsible for changes elsewhere?

Like mesquite, creosote bushes can create "islands of fertility"—small nutrient-rich patches that grow at the expense of the surrounding land, turning it almost lifeless.

The first glimmers of an answer came in 1988, on an afternoon when the senior Jornada researchers closeted themselves in a hotel room in Columbus, Ohio, during an ecology meeting. That day, in the course of their long conversations, they first realized that they had all noticed a simple but important pattern in the Jornada: the desert is patchy. Its vegetation is obviously patchy even to the untrained eye, looking like an archipelago in a drained ocean. But the researchers had discovered that the desert is also patchy in unseen ways, such as in the distribution of its water, nutrients, and microbes. Grasslands, on the other hand, are relatively uniform carpets of plants and resources. Find what drives an ecosystem from smooth to patchy, the Jornada researchers decided that afternoon, and you've explained desertification.

Over the next several years they constructed something they call the Jornada model, based on observations, experiments, and intuition. Like all models, it is a story, and it begins in the 1800s, when the basin was a grassland. Though its climate was precariously dry, the ecosystem had remained stable for millennia, thanks in part to its ability to create its own weather. Its spongy soil soaked up rain, and when the water evaporated back into the air, it formed clouds that then recycled the rain back to the basin.

The grassland was also able to shut out competing plants. While a few creosote bushes and mesquite trees grew in the basin, they had a tenuous existence. "They're a native element that was always there, just waiting," says Havstad. Shrub seedlings, though, were particularly vulnerable to the fires that swept the grassland, and the ones that survived faced a crippling water shortage: the shallow, dense roots of the grass absorbed the rain before it could percolate down to the shrubs' deeper roots.

In the late 1800s the vast unmanaged herds of cattle that were made possible by the advanced drilling technology helped the shrubs penetrate the grassland's defenses. Simply by eating the grass, the cattle impaired its ability to photosynthesize and grow. Less obviously—but just as important—they may well have made the landscape patchy. The ecologists speculate that as the cattle trampled the ground to their favorite feeding spots, the ground they habitually walked on became less

"The ranching industry doesn't like us at all. They'd love to say that cows make no difference, that it's all drought or climate change or

able to absorb water. Rain flowed over this soil rather than into it, forming channels. No longer lingering in the upper soil, where grass roots grew, the water instead either escaped downstream or percolated through the channel bottoms, down to where only the deep-rooted shrubs could get to it. Hoofprints gave rise to pools of water that infiltrated the soil, creating spots for a seedling to take root and thrive. Water was no longer evenly spread over the basin, but now concentrated in scattered places.

By the time the giant herds left the Jornada, they had pushed it over a critical threshold. Now the ecology of the desert itself took up where outside influences left off. Thanks to patchiness, shrubs established a foothold, and they made the patchiness even greater.

"The shrubs are deeply and widely rooted," explains Schlesinger, "so they're obtaining nitrogen from a big area of the desert. It's at low concentrations out there, but they're getting it and concentrating it in their tissues. Then as the shrubs drop their leaves, the leaves fall under the shrub. It's like a pumping mechanism. They're sucking nutrients in from far and wide and dumping them under their canopies. The leaves decompose under the shrub and the nitrogen gets circulated. The bulk of the nitrogen is what gets circulated from under the shrub, but every year there's new nitrogen that's also being added from these roots."

The shrubs rearranged the nitrogen in the basin from a smooth layer to concentrated and increasingly isolated "islands of fertility." Wind and rain began to make these islands grow faster. Gusts scoured the bare patches, carrying away nutrient-rich dust, but when they hit the canopies of creosote and mesquite, they broke into whirling, weakened eddies, dropping their dust—as well as dead leaves and other organic matter—to the base of the shrubs. When a raindrop hit unprotected soil, it shoveled up the topsoil and carried it away in the overland flow of water, and when the water hit the downslope edge of the patch, it carved away even more soil. But the shrub roots protected their islands from the flow, and their leaves broke the fall of raindrops, which dribbled gently to the spongy ground below.

The mesquite and creosote also brought animals adapted to them, which in their own ways helped the islands grow. Termites and kangaroo rats collected food from a wide range and stored it in their nests, which they often made under shrubs. In this way they brought a lot of organic matter into the islands and took it away from surrounding areas. Meanwhile, nests they established away from the shrubs often became ideal birthplaces for new seedlings.

Even the shape of an insect's mouth could help build the desert. "In a grassland, most of the processing is done by chewers," says Whitford, and the droppings of these grassland insects—the scientific term is *frass*—consist of tough, complex material that spreads over the ground before it finally breaks down. "But the insects you find on shrubs," he explains, "are predominantly guys with mouthparts like little hypodermic needles, and they're sticking them directly into the vascular system of the plant and siphoning off its sap. The frass is basically a simple sugar solution. When that hits the soil, you've got a ready source of energy for the microbes to use and break down into the soil, where it's available for growing plants."

According to the model, all these feedback cycles will eventually, over the course of millennia, reach an equilibrium in the Jornada. When a shrub dies, the island it leaves will be a nursery for a new one, which will be protected from fire by the distance from one island to the next. Neither hard, bare soil nor shrub-dominated islands will offer any hope to colonizing grass. And since the soil will hold less and less water, rain recycling will stop, making the desert even drier.

Rain erodes the bare, hard soil of deserts, but plants can offer some protection. To determine how much, researchers collect sediment washed from staked-out plots.

Ecology being such a slow science, the researchers knew that by proposing this model they were indenturing themselves for decades. Seven years after their first brainstorm, they sound hopeful. "Just about all the evidence we've collected so far supports it," says Reynolds. New Mexico State University biologist Laura Huenneke, for example, has been measuring the mass of the Jornada vegetation, and she finds that the central tenet of the model holds true: arid grassland and shrub-dominated desert contain about the same weight of plant material. It's just arranged differently.

The researchers even feel confident enough now to argue that the Jornada model explains desertification in other parts of the world. The grass may not be black grama and the shrubs may not be mesquite and creosote, but the basic process seems universal.

The model also ought to apply to the spread of deserts before humans began to change the landscape, with slow shifts of climate playing the role of grazing cattle. As a grassland experienced centuries of decreasing rainfall, this scenario goes, the upper level of the soil would dry out. Grasses, with their shallow roots, would suffer, but shrubs would still be able to tap the deep water that trickled into the ground from storm runoff, and they'd start building their islands. A simultaneous change in the composition of the atmosphere could speed the process. Grasses are much more efficient absorbers of carbon dioxide than are plants like mesquite and creosote, and so they can thrive on low levels of the gas. But when the atmospheric level of CO_2 jumped from time to time, grasslands lost their competitive advantage and became vulnerable to shrubs and patchiness.

With an average of only nine inches of rain a year, the Jornada is always in danger of drought. "Rain-out shelters" allow ecologists to see how well plants will survive.

As they test the model further, the researchers crawl over the basin like a swarm of locusts. Schlesinger and Raikes, for example, bang their pipes into the dirt and find it fascinating because they want to see how the distribution of chemicals in desert soil changes over millennia. The model predicts that the chemicals important to life get concentrated under vegetation, while unnecessary elements like lithium and bromine remain smoothly scattered. Schlesinger is collecting soil samples from Jornada grassland and shrub land and comparing them with samples from the Mojave Desert in California, where a dry climate has allowed creosote to build islands of fertility for 10,000 years. If the model is right, he should see a progression in the distribution of chemicals from young desert to old.

However, it is not these last stages of the model that are most controversial, but the first ones—in which grazing supposedly gives islands of fertility their start. The human causes of desertification and their cures have attracted vast amounts of money and prompted political wrangling. Billions of dollars have already been spent in various schemes to fight desertification, even though researchers are only beginning to understand how it works. Critics maintain that developing countries use the fear of spreading deserts as a way to guarantee a flow of aid. But the argument isn't limited to Third World nations. In the United States, environmental groups are urging Secretary Babbitt to increase fees for grazing on the 280 million acres of public rangeland. Cheap grazing rights, they say, degrade the land, drive species extinct, and lead to desertification. Ranchers claim that they've improved their grazing practices since the turn of the century, so that the only real effect of raising grazing fees will be their bankruptcy.

The Jornada researchers try their best to keep the hue and cry from affecting their work. "The ranching industry doesn't like us at all," says Schlesinger. "They'd love to say that cows make no difference, that it's all drought or climate change or kangaroo rats. But I don't see these things as mutually exclusive. There's no point in our singling out one thing at the expense of others."

"The debate has a hell of a lot less to do with science than emotion," says Whitford. "It's about economics, about whose ox is getting gored. Hopefully we can provide some factual information. We don't have unequivocal evidence that there are these links; that's why we're doing the experiments we're doing."

So far those experiments have given them results that are suggestive but not conclusive. In 1982 the Jornada ecologists closed off some plots from the USDA's cattle. Over the following ten years many of the plots that still had some grass in them dramatically improved, compared with unprotected grass nearby; meanwhile, shrub-dominated plots saw no change. Still, some of the plots untouched by cows also died out, suggesting that drought too must play a role in the long-term survival of grassland.

However, New Mexico State University ecologist William Conley has shown that droughts may not have been so important in the Jornada. Grass is indeed susceptible to drought, but only when it strikes during the summer growing season. The USDA's 80-year record of rainfall in the basin shows that droughts this century have actually hit the Jornada more during the winter, the growing season of mesquite and creosote. If any-

kangaroo rats. But I don't see them as mutually exclusive. There's no point in our singling out one thing at the expense of others."

Though desert has spread over most of the Jornada Basin, a few stretches of black grama grass remain. In the distance, however, is an encroaching swath of creosote.

thing, they should have helped the grassland survive. Conley also made a statistical analysis of the rainfall record that shows that the droughts were not freakish; they had probably hit the Jornada every few decades for centuries. If they had the power to desertify, the Jornada should have become a desert long before Mexicans first passed through it.

That leaves grazing as the most likely culprit. Only now, though, are the Jornada ecologists performing the experiment that can document the steps by which cattle may initiate islands of fertility. Almost dead center in the basin, a wave of mesquite is rolling over some of the last remaining black grama. In 1993, on the border between the two plant communities, USDA researchers set up 18 fenced enclosures, each about 750 feet square. In 9 enclosures they hacked down the mesquite and painted the stumps with herbicide; the other 9 sites were left untouched. Whitford, who has continued to study the Jornada since he joined the Environmental Protection Agency in 1992, cataloged all the plants and animals. Schlesinger, who with Reynolds now heads the Jornada Long-Term Ecological Research Project, measured the distribution of dozens of chemicals in the soil. Before this winter is over, Havstad will bring two dozen head of cattle into 6 of the corrals and let them graze for 24 hours, in which time they should devour two-thirds of the grass and trample the ground. This summer he will let them loose in 6 others, while the 6 remaining will stay unmolested. In the next five years the researchers will measure how the soil, plants, and animals change in response. Two of the grazed plots will be burned and 2 others will be covered in rain-out shelters to see how fires and droughts enhance or reduce the effects of grazing.

If the story of the Jornada does turn out to be the story of other deserts, then ecologists should be able to foretell the story of deserts not yet born. And that's a skill that may be in high demand in the coming decades. As we burn fossil fuels and add carbon dioxide to the atmosphere, we once again take away the competitive advantage grass has in a CO_2-poor world. Simulations also suggest that global warming may make continental interiors drier. Grasslands that now get comfortable levels of rain may become vulnerable to grazing, as the Jornada was in the nineteenth century.

For over 20 years Reynolds has been turning data collected in the Jornada into mathematical equations. By calculating 200 variables, he can now accurately simulate the year-to-year evolution of a few square yards of the Jornada, whether it's occupied by grass, an island of fertility, or bare soil. Now he's stitching these patches together into a quilt that represents the entire basin. Using its actual topography and weather, he lets the patches interact. Shrubs deplete the surrounding soil, and bare patches help erode neighboring topsoil as water flows from one patch to the next. By measuring the growth of creosote and mesquite in an isolated, CO_2-flooded area, Reynolds hopes to be able to predict how the basin will evolve in the near future.

Ultimately the simulation should be able to predict the fate of any grassland. An ecologist in Chile, for instance, could feed a computer data on the local topography, weather patterns, and patterns of vegetation and see how likely the land would be to shift over to desert. "We'll be able to say how sensitive places will be to grazing and climate change," says Reynolds. "We can say, this area is not beyond the threshold and it would be worth trying to restore it, but this other area has changes that are irreversible."

Irreversible is a tough word, but the Jornada model makes clear why most efforts to restore self-sustaining grasslands are futile. Take away the shrubs, and the landscape, full of islands of fertility, is still perfectly suited for new creosote and mesquite to invade. "We've talked about a homogenization experiment," says Reynolds, "in which we'd go out to some of the big dunes where it's really heterogeneous and just bulldoze those babies and see if when you distribute everything, the grasses would be successful again. This would just be an academic pursuit; it wouldn't be a restoration tool." Deserts do turn to grasslands naturally, but only when thousands of years of steadily increasing rainfall counteracts the power of the islands of fertility.

Perhaps the name Jornada del Muerto should now be changed to Jornada del Desierto. Just as people have journeyed across the basin for centuries, the land itself is taking a journey that these researchers are now able to trace. According to Whitford, history may provide a glimpse of its destination.

"Climatically, North Africa should be a grassland savanna," he says. "You can go back to historical records and read about the trees on the mountains and lush grass, about how they were the breadbasket for Rome, providing grain and meat to the empire. Well, now it looks like parts of Nevada. You put these things together and say, 'Well, the model probably worked there, and it looks like it followed the trajectory that we're following in places like the Jornada.' We're well on our way." D

The Jornada LTER also publishes its own newsletter of important progress, achievements and regional events. Four issues of the newsletter, known as Jornada Trails are included herewith.

JORNADA TRAILS

Jornada Long-Term Ecological Research Program

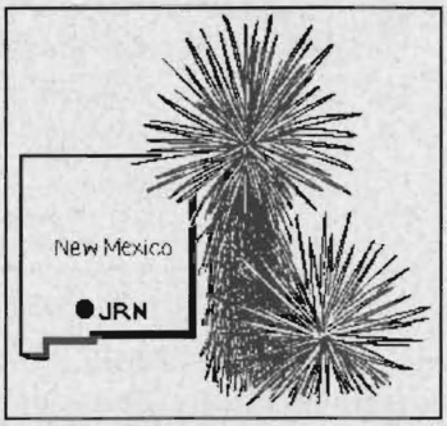
Volume 1 Issue 1, September 1995

Jornada Site Hosts Wildland Shrub Symposium

In late May 1995, the Las Cruces Hilton was the scene of the 9th Wildland Shrub Symposium, sponsored by the Shrub Consortium, New Mexico State University, the USDA Agricultural Research Service, and the Jornada LTER program. More than 150 scientists from the southwestern U.S. gathered to exchange current ideas regarding the management of arid and semiarid ecosystems, especially desert shrublands. The meeting included a midweek tour of the Jornada Experimental Range, where USDA, NMSU and LTER researchers described current field studies in southern New Mexico and participants enjoyed an evening barbecue under the setting Sun.

Among featured speakers of the symposium, Julio Betancourt of the U.S. Geological Survey (Tucson) showed how climate fluctuations in the Holocene have controlled the frequency of fire in natural ecosystems of the Southwest.

Kris Havstad (Jornada Experimental Range, ARS) described his recent efforts to salvage and preserve historic data sets that describe the distribution of vegetation on quadrats established at the Jornada in the early part of this century. LTER Principal Investigator William Schlesinger (Duke University) showed how changes in arid lands are important feedbacks to climate change—both regionally and globally, and Herman Mayeux (USDA) discussed some of the potential responses of desert shrubs to rising atmospheric carbon dioxide.



The Jornada LTER Program is an NSF-funded project.

> ***"The maps left by early range scientists are a priceless long-term data set."—Kris Havstad***

The proceedings of the entire symposium will be published by the U.S. Forest Service as a Technical Report from the Intermountain Station.

Jornada LTER Featured in *Discover* Article

Research at the Jornada was featured in the February 1995 issue of *Discover* magazine. In "How To Make a Desert," senior science editor Carl Zimmer summarized the cooperative efforts between the LTER scientists and staff researchers of the USDA Jornada Experimental Range.

Zimmer spent several intensive days with LTER researchers last summer, followed by a photographer on assignment for the magazine.

Discover is a national magazine covering science and technology news for adults without a scientific background. It has a circulation of one million.

As Zimmer's article shows, the basic hypothesis for long-term research at the Jornada is that the ongoing desertification process is accompanied by changes in the spatial distribution of water and soil nutrients—from a uniform distribution in grassland to a patchy distribution in shrublands.

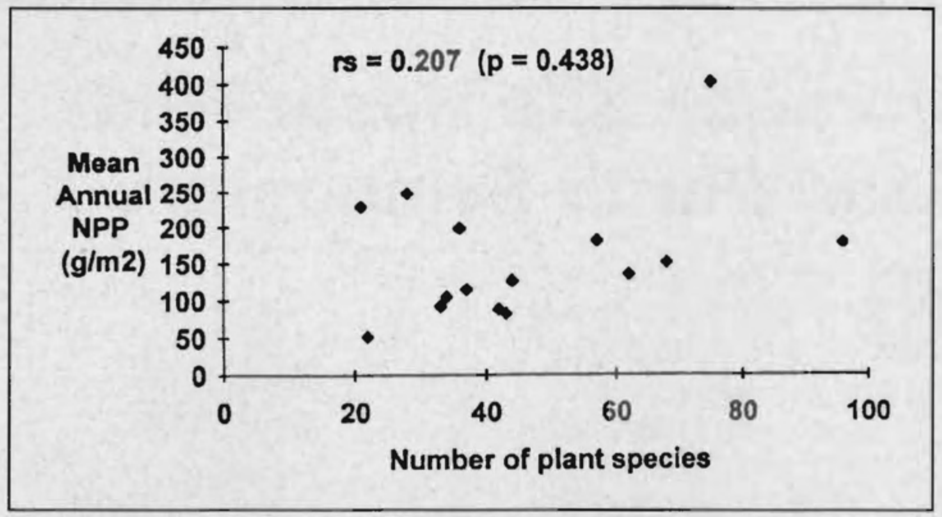
The article quotes Kris Havstad, director of the Jornada Experimental Range, on the historic impacts that humans inflicted on the landscape of New Mexico: "After water was brought to

(Continued on page 3)

inside...

Huenneke Represents Jornada LTER at Recent Scientific Meetings

LTER coinvestigator Laura Huenneke has represented the Jornada at a variety of recent meetings held to assess the importance of biodiversity to ecosystem function. Laura's own work at the Jornada indicates no clear relationship between the number of species present in a particular community and levels of ecosystem function, such as net primary productivity (see figure). Thus, Laura shows that the invasion of semiarid grasslands by desert shrubs is accompanied by a loss of species, without a loss of regional net primary production.



Net primary production as a function of species diversity in habitats of the Jornada basin

Working with Ian Noble (Australian National University), Laura has coauthored recent chapters in the United Nations Environmental Program's (UNEP) assessment of the global importance of biodiversity. With William Schlesinger (Duke University) she has represented the Jornada at meetings of The Americas Interhemispheric Geo-Biosphere Organization (AMIGO) and the InterAmerican Institute (IAI) for Global Change Research—both of which seek to foster cooperative studies between the South America, Latin America and the United States in global change research.

Welcome to New LTER Investigators at the Jornada Program

The Jornada LTER welcomes these new investigators, who joined us in 1995:

Athol Abrahams, State University of New York at Buffalo (Studies of hydrologic transport in the Jornada basin)

Dale Gillette, NASA, Research Triangle Park, N.C. (Studies of soil crusts as determinants of wind erosion in the Jornada Basin)

Vince Gutschick, New Mexico State University (Studies of atmosphere-vegetation interactions)

David Lightfoot, University of New Mexico, Albuquerque (Studies of small mammals as agents of soil heterogeneity in desert environments)

Curtis Monger, New Mexico State University. (Studies of soil development in Quaternary environments of the Jornada basin)

JORNADA TRAILS

***Jornada Trails* is a biannual publication of the Jornada Long-Term Ecological Research (LTER) Program, sponsored by the National Science Foundation.**

Stories and story ideas are welcome! Send them to:

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REU Program

Undergraduates Get Hands-On Field Experience with Jornada Scientists

Summer 1995 brought a number of undergraduate students to the Jornada Experimental Range as part of the Research Experience For Undergraduates (REU) program of the National Science Foundation.

Kevin Gross (Duke University) and Josh Mooney (Dartmouth College) examined the comparative rates of decomposition of shrub litter as a function of experimental manipulations of soil moisture in rainout shelters.

NSF-sponsored program gets undergraduates into the field with scientists as mentors

Scott McCabe (SUNY, Buffalo) is developing a model to predict overland flow on irregular desert hillslopes under different rainfall regimes. He is working in cooperation with Dr. Athol Abrahams in the Department of Geography.

Visiting scientific teams also contributed to the REU program at the Jornada. Working with Jim Winsor of Penn State University (Altoona), Shani Peretz examined the pollination biology of the desert "buffalo" gourds as a function of herbivory and the timing of flowering relative to the onset of summer drought conditions.

Discover Article

(Continued from page 1)

the surface in the 1880s, there were 20,000 head of cattle out here. This place just got hammered." LTER principal investigator William Schlesinger is quoted as believing that cattle helped spur the spatial redistribution of soil resources, leading to the invasion of shrubs.

The *Discover* article describes how the LTER research at the Jornada is relevant to the current controversy concerning grazing rights and the management of western lands.

A new experiment, established cooperatively with researchers from the Environmental Protection Agency, will subject areas of desert grassland to intense grazing by cattle at different seasons. The goal is to assess the rate of shrub invasion and changes in the distribution of soil resources. Despite droughty conditions at the site, USDA personnel were able to initiate the first grazing treatment in February, and they hope to conduct the summer treatment this month.

Recent Publications from Jornada Investigators

Fredrickson, E., J. Thilsted, R. Estell and K. **Havstad**. 1994. Effects of chronic ingestion of tarbush (*Flourensia cernua*) on ewe lambs. *Veterinary and Human Toxicology* 36: 409–415.

Gallardo, A. and W. H. **Schlesinger**. 1995. Factors determining soil microbial biomass and nutrient immobilization in desert soils. *Biogeochemistry* 28: 55–68.

Herman, P. P., K. R. Provencio, J. Herrera-Matos and R. J. Torrez. 1995. Resource islands predict the distribution of heterotrophic bacteria in Chihuahuan desert soils. *Applied and Environmental Microbiology* 61: 1816–1821.

Li, H. and J. F. **Reynolds**. 1995. On definition and quantification of heterogeneity. *Oikos* 72: 1–5.

Nash, M. H. and W. G. **Whitford**. 1995. Subterranean termites: Regulators of soil organic matter in the Chihuahuan desert. *Biology and Fertility of Soils* 19: 15–18.

Duke Grad Student Awarded ESA Grant

Roberto Fernandez, a Duke graduate student working with James Reynolds, has been granted a $1,000 Forrest Shreve Desert Research Award by the Ecological Society of America.

The title of Roberto's proposal was "Why has grass cover in the Northern Chihuahuan Desert decreased over the past 150 years? A test of the xerophytism vs. palatability hypothesis." Roberto began field work at the Jornada in June of this year.

Featured Investigator

Peter Herman of New Mexico State University

Each issue of *Jornada Trails* will highlight the work of an LTER investigator. New Mexico State University Associate Professor of Biology Peter Herman is our first featured investigator.

Recently, Peter's article in *Applied and Environmental Microbiology* was selected for special mention in the July Newsletter of the American Society of Microbiology. In his paper, Peter shows that the guild of soil microbes is distributed relatively uniformly in desert grassland soils, but very heterogeneously in adjacent shrublands. Peter's paper not only provides basic support for the underlying hypothesis of desertification at the Jornada, but also illustrates the importance of local-scale heterogeneity that has been ignored by many soil microbiologists.

Peter Herman

Expanding his work to new horizons, Peter will spend the 1995–96 academic year at the Swedish University of Agricultural Sciences, where he will examine the spatial distribution of soil microbial activity in pastures that are being invaded by shrubs. He has recently been awarded $40,000 from the National Science Foundation to further his comparative work on soil microbial processes at the Jornada and in Sweden.

JORNADA TRAILS

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JORNADA TRAILS

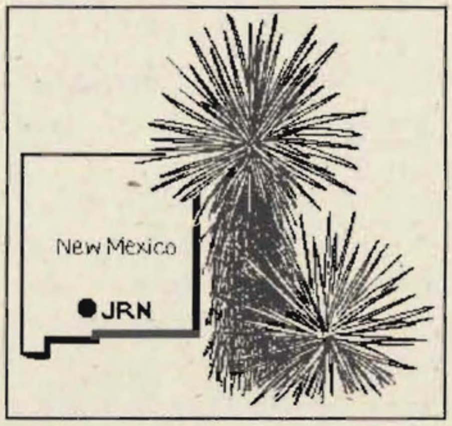
Jornada Long-Term Ecological Research Program Volume 2 Issue 1, March 1996

Jornada Results Presented at Nairobi Meeting

Jornada investigators were asked to present a keynote paper at the international UNEP conference: Combating Global Warming by Combating Land Degradation. This meeting brought twenty specialists from nine countries to Nairobi, Kenya, for a week-long workshop in September of last year.

Sean Connin presented the Jornada results in a paper entitled "Dynamics of Carbon Storage in Degraded Arid Land Environments." He reviewed changes in the total amount of carbon stored in vegetation and soils in the Jornada basin by comparing the carbon content of present-day grasslands to that held in shrubland ecosystems. Surprisingly, there has been little overall change in carbon storage during the last 100 years.

> ***"Arid land crop management offers little potential to mitigate rising atmospheric CO_2 concentrations."***
> ***—Sean Connin***



The Jornada LTER Program is an NSF-funded project.

The Jornada results were particularly relevant to the conference because various scientists have suggested planting shrubs in arid lands as a means of sequestering carbon dioxide from the atmosphere. But Connin and his coworkers concluded that "soil carbon storage through halophyte production, related energy costs, and landscape disturbance associated with cultivation indicate that arid land crop management offers little potential to mitigate rising atmospheric CO_2 concentrations."

The conference proceedings, with this paper, will be published next year by the University of Arizona Press. *Contributed by Sean Connin, Dartmouth College*

Geostatistics Work Appears in *Ecology*

One of the basic postulates of the Jornada LTER research program is that the invasion of desert grasslands by shrubs results in a change in the spatial heterogeneity of soil nutrients. The resulting "patches" of nutrient-rich soil become favored sites for the regeneration and persistence of shrubs in the desertified landscape.

Jornada investigators William H. Schlesinger, Jane A. Raikes, Anne E. Hartley, and Anne F. Cross provide a much-needed test of this hypothesis in research reported in the March 1996 issue of *Ecology*. These researchers used geostatistics to show the scale of soil nutrient patches in adjacent grassland and shrubland habitats in several areas of the desert Southwest.

Their study examines nutrient distributions at three sites in the LTER network—the Central Plains grassland (CPR), the Sevilleta (SEV), and the Jornada (JRN)—as well as sites in the Mojave Desert of California and the Great Basin Desert near Reno.

For sites located in New Mexico, the team found that a non-essential plant nutrient, chloride, is distributed

(Continued on page 3)

inside...

Friends of Jornada Symposium Set

The Annual "Friends of the Jornada" symposium will be held at New Mexico State University on May 23, 1996. This year, returning to its traditional format, the symposium will feature a day-long slate of research presentations by Jornada investigators and their students, followed by an evening barbecue at the Headquarters of the USDA Jornada Experimental Range. Speakers will make informal presentations about their latest research findings and their ideas for future summer study.

There is a registration fee of $5.00. For further details, contact Kris Havstad (Khavstad@nmsu.edu) at the Jornada Experimental Range.

NSF Awards Grants for Two Cross-Site Studies at Jornada LTER Site

Two proposals involving the Jornada LTER site were successful in last fall's NSF competition for cross-site studies. With nearly $200,000 of new funding from NSF, Jornada investigator David Lightfoot will extend his studies of the effects of small mammals on desertification by establishing a site for comparative studies in Mapimi, Mexico.

Dave is testing the hypothesis, first proposed by Jim Brown at the University of New Mexico, that the exclusion of kangaroo rats from desert shrublands allows arid grasses to recolonize former grassland habitats. His work involves extensive areas of rodent exclusion at the Jornada and Sevilleta LTER sites. Similar study plots will now be established in Mexico.

Separately, John Wiens of Colorado State University was awarded $200,000 to begin comparative studies of ant communities at the Central Plains, Sevilleta, and Jornada LTER sites. John's studies will examine the changes in ant community structure that accompany changes in the spatial distribution of soil resources in grassland and shrubland habitats.

Jornada LTER On the World Wide Web

The Jornada LTER program now maintains a site on World Wide Web that can be accessed at the following URLs:

http://jornada.nmsu.edu
http://lternet.edu/about/sites/09_jrn.htm

The site features an up-to-date listing of the long-term data sets maintained by the Jornada Research Program with access to those data sets that are available for public use.

The site also includes the text of the Jornada LTER annual report, staff listings, and links to other LTER WWW sites.

Duke Grad Student Awarded ESA Grant

After our last issue went to press, *Jornada Trails* learned that Adrienne Pilmanis, a graduate student in botany at Duke University, received a $1000 award from the Ecological Society of America.

The award was made from the Society's Forrest Shreve Fund to support student research in the desert Southwest.

Adrienne is examining changes in the distribution of soil nutrients that accompany fires and the invasion of mesquite in desert grass-lands at the Jornada. She began her work in the summer of 1995 and will visit the Jornada again this year.

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Copyediting, design, and layout by Lisa M. Dellwo

Recent Publications from the Jornada

de Soyza, A. G., A. C. Franco, **R. A. Virginia**, **J. F. Reynolds**, and **W. G. Whitford**. 1996. Effects of plant size on photosynthesis and water relations in the desert shrub Prosopis glandulosa (Fabaceae). *American Journal of Botany* 83: 99-105.

Fredrickson, E. L., R. E. Estell, **K. M. Havstad**, W. L. Shupe, and L. W. Murray. 1995. Potential toxicity and feed value of onions for sheep. *Livestock Production Science* 42: 45-54.

Huenneke, L. F. and I. R. Noble. 1995. Arid and semi-arid lands. pp. 349-354. In V. H. Heywood (ed.). *Global Biodiversity Assessment*. Cambridge University Press, Cambridge.

Schlesinger, W. H., J. A. Raikes, A. E. Hartley, and A. F. Cross. 1996. On the spatial pattern of soil nutrients in desert ecosystems. *Ecology* 77: 364-374.

Sheets, K. R. and J. M. H. Hendrickx. 1995. Noninvasive soil water content measurement using electromagnetic induction. *Water Resources Research* 31: 2401-2409.

Thomas, P. M., K. F. Golly, **R. A. Virginia**, and J. W. Zyskind. 1995. Cloning of nod gene regions from mesquite rhizobia and bradyrhizobia and nucleotide sequence of the nodD gene from mesquite rhizobia. *Applied and Environmental Microbiology* 61: 3422-3429.

Whitford, W. G., G. S. Forbes, and G. I. Kerley. 1995. Diversity, spatial variability and functional roles of invertebrates in desert grassland ecosystems. pp. 152-195. In M. McClaran and T. R. Van Devender (eds.). *The Desert Grassland*. University of Arizona Press, Tucson.

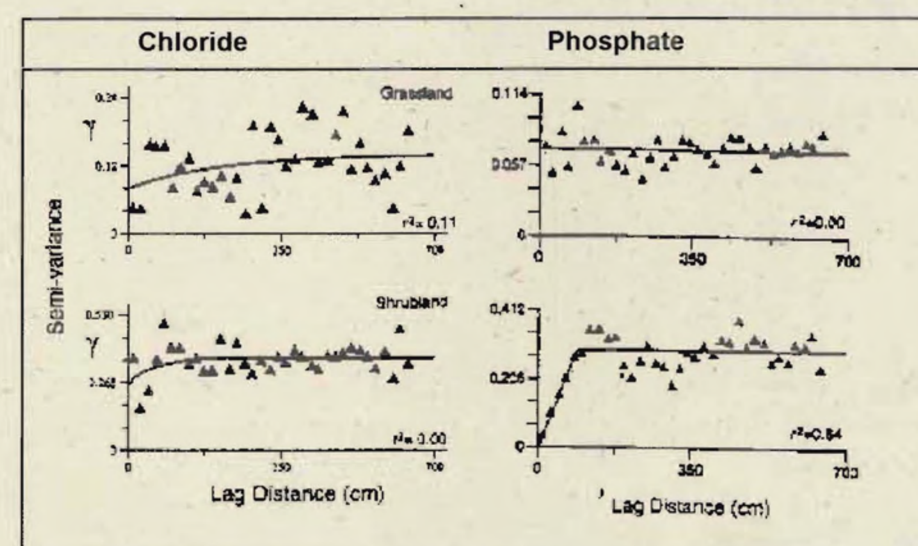
Geostatistics Work Appears in *Ecology*

(Continued from page 1)

randomly in all communities, whereas in shrublands, soil phosphorus shows marked patches in its spatial distribution that are associated with the average size of creosotebush. (See figure.) In shrublands, the spatial distribution of soil nitrogen is also strongly related to the size and distribution of shrubs.

The development of soil patchiness is less extreme in the recently desertified habitats of the Chihuahuan Desert than in the more arid Mojave Desert.

Surprisingly, patchy nutrient distributions were found at the CPR as well, but the scale of patchiness is fine-grained and apparently associated with the size of clumping in the bunch grasses.



Book Review

Sonoran Desert Plants

Turner, R. M., J. E. Bowers, and Tony L. Burgess. 1995. *Sonoran Desert Plants: An Ecological Atlas*. University of Arizona Press, Tucson. 1-800-426-3797. xvii + 504 pp., illus., $70.00.

All serious desert ecologists will want to own this long-awaited volume by Ray Turner and his coworkers at the Desert Lab in Tucson. Many of the Sonoran species are also found at the Jornada, making the book essential for students of the Chihuahuan Desert as well.

For each species, Turner et al. provide a brief description of its field ecology and distribution, a range map compiled from herbarium specimens and published sightings, and a graph showing the distribution of each record as a function of altitude. These will provide a cornucopia of ideas for field physiological studies to understand the controls on plant distribution. Looking at these maps, it takes little imagination to see how global climate change may impact vegetation in the desert Southwest.

Featured Investigators

Athol Abrahams of SUNY-Buffalo & His Team

This issue of *Jornada Trails* recognizes the research team of Athol D. Abrahams (SUNY- Buffalo), Tony Parsons (U. Keele, UK) and John Wainwright (King's College, London) as its featured investigators. Working together for many years at the USDA's Walnut Gulch research station in southeastern Arizona, these workers are recent additions to the Jornada LTER team. They hope to extend their studies of runoff and sediment transport to a broad area of the desert Southwest.

Athol and his coworkers are the authors of a late-1995 paper in *Geomorphology* that shows that the invasion of desert grasslands by shrubs causes increased erosion from the "interrill" areas, by decreasing resistance to overland flow. This erosion increases the spatial heterogeneity of nutrients in desert soils.

Athol Abrahams

Last summer, Athol and his coworkers performed a number of rainfall simulation experiments at the Jornada, in which the runoff waters were collected for measurements of the loss of nitrogen, phosphorus and other soil nutrients from soils in grassland and shrubland habitats.

The Jornada welcomes these prolific and talented scientists as co-investigators on its current LTER grant.

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Jornada Long-Term Ecological Research Program

Volume 2 Issue 2, October 1996

Major Winter Dust Storm Recorded at the Jornada

In 1995, Dale Gillette, a new collaborator in the Jornada research program, established a station to provide a long-term record of wind erosion and dust transport for the LTER program. It was just in time! On January 17, 1996, with winds gusting to 60 miles per hour, a major dust storm swept the Jornada Basin. Total particle transport recorded by Gillette's instruments was nearly 25,000 g/cm during the dust storm, compared to rates of only 100 g/cm in more normal conditions (see figure, page 3).

Much of the material captured in dunes may arrive during periods of high wind velocity.

The transport of wind-borne material from arid regions is the subject of several recent papers that attempt to incorporate the effects of suspended dust in general circulation models of global warming. Dust over barren land surfaces typically has a warming effect on the atmosphere, while over oceans the reverse is true. Recent studies by Robert Swap (U. Va.) in the western Sahara desert show that much of the dust transport over the Atlantic ocean occurs in episodic events. Similarly, the January 17 event at the Jornada was associated with an unusual southward-dipping cold front over most the western U.S. Episodes of dust transport, such as that seen at the Jornada, will be challenging to incorporate into long-term models of global climate.

These episodes of soil transport are also important for understanding the dynamics of shrub ecosystems in the Jornada basin. The invasion of mesquite is associated with the development of large dunes around the base

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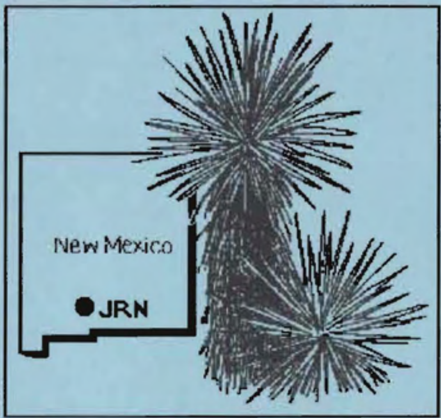

The Jornada LTER Program is an NSF-funded project.

Jornada Researchers Present Papers at the ESA Annual Meeting

A variety of papers by LTER researchers highlighted the program at the annual meeting of the Ecological Society of America in Providence, Rhode Island, August 9–12, 1996. Especially significant results were reported in a poster presented by Jim Reynolds and his colleagues, who used "rainout" shelters to prevent either summer or winter rain from entering the soil profile around shrubs and then monitored shrub growth for several years. They found that despite the large proportion of total annual rain that falls during large summer thundershowers, it is the recharge of the soil profile by the smaller winter rains that is most significant to shrub growth.

Greater shrub growth during multi-year periods of unusually high winter rainfall is also seen in southeastern Arizona, where Jim Brown and his colleagues have examined changes in vegetation cover for the last several decades. In a mirror image to these recent findings, about a decade ago Ron Neilsen, then a postdoctoral associate with the Jornada LTER, found that the recruitment of black grama grass de-

(Continued on page 3)

inside...

Recent Publications from the Jornada

Floyd, T. 1996. Top-down impacts on creosotebush herbivores in a spatially and temporally complex environment. *Ecology* 77: 1544–1555.

King, D. W., R. E. Estell, E. L. Fredrickson, **K. M. Havstad**, J. D. Wallace, and L. W. Murray. 1996. Effects of *Flourensia cernua* ingestion on intake, digesta kinetics, and ruminal fermentation of sheep consuming tobosa. *Journal of Range Management* 44: 325–330.

King, D. W., E. L. Fredrickson, R. E. Estell, **K. M. Havstad**, J. D. Wallace, and L. W. Murray. 1996. Effect of *Flourensia cernua* ingestion on nitrogen balance of sheep consuming tobosa. *Journal of Range Management* 49: 331–335.

Mack, G. H., W. C. McIntosh, M. R. Leeder, and **H. C. Monger**. 1996. Plio-Pleistocene pumice floods in the ancestral Rio Grande, southern Rio Grande rift, USA. *Sedimentary Geology* 103: 1–8.

Phinn, S., J. Franklin, A. Hope, D. Stow, and **L. F. Huenneke**. 1996. Biomass distribution mapping using airborne digital video imagery and spatial statistics in a semi-arid environment. *Journal of Environmental Management* 47: 139–164.

Reynolds, J. F., R. A. Virginia, and **W. H. Schlesinger**. 1996. Defining functional types for models of desertification. pp. 194–215. In T. M. Smith, H. H. Shugart and F. I. Woodward (eds.). *Plant Functional Types*. Cambridge University Press.

Schlesinger, W. H. and N. Gramenopoulos. 1996. Archival photographs show no climate-induced changes in woody vegetation in the Sudan, 1943–1994. *Global Change Biology* 2: 137–141.

JORNADA TRAILS

***Jornada Trails* is a biannual publication of the Jornada Long-Term Ecological Research (LTER) Program, sponsored by the National Science Foundation. Stories and story ideas are welcome! Send them to:**

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***Jornada Trails* also appears on the World Wide Web at http://jornada.nmsu.edu or http://lternet.edu/about/sites/09_jrn.htm**

Copyediting, design, and layout by Lisa M. Dellwo

New Mexico Biodiversity Report Available

Increasing public interest in the decline of biological diversity in New Mexico led the New Mexico Academy of Sciences to devote its 1996 volume of *The New Mexico Journal of Science* to a general assessment of biodiversity in the state.

The special issue, entitled "New Mexico's Natural Heritage," was edited by Jornada LTER investigator Laura Huenneke, and it contains chapters discussing the diversity of important taxonomic groups and environmental change in New Mexico's important ecosystems.

There are also detailed case histories of conservation efforts for several rare plant and animal species and chapters describing the activities of governmental and nonprofit conservation agencies to promote species persistence.

The *Journal* will be released at the Academy's annual symposium in Albuquerque in November, and it will be distributed to educational institutions throughout the state.

Individuals who wish to purchase a copy should send $10.00 to the Department of Biology, New Mexico State University, Las Cruces, NM 88003.

Contributed by Laura F. Huenneke, Department of Biology, New Mexico State University

The JORNEX Project

Quantifying Hydrological Dynamics in the Jornada Basin

Scientists from ten locations, including five USDA/ARS research units and the Staring Centre in Wageningen, The Netherlands, are working together to quantify the dynamics of land surface hydrology and energy balance in the desert rangeland in the Jornada Basin. These studies are integrating different types of remote sensing data and detailed micrometeorological and vegetation data to quantify moisture and energy fluxes over a 4000-ha area where desert grasslands degrade into mesquite dunelands.

Five intensive campaigns were conducted during the summer growing seasons and dormant winter periods in 1995 and 1996. Airborne data included three-camera multi-spectral (visible yellow-green, red and near-infrared) video images recorded digitally from a fixed wing aircraft at 300, 750 and 1500 m altitude. A thermal infrared radiometer and a 4-band (corresponding to the first 4 bands of the Landsat Thematic Mapper) radiometer were used to make radiance measurements at 125 and 300 m, and a laser altimeter collected imagery at 125 and 300 m. Ground data included vegetation cover, spectral reflectance, composition and height; leaf-area indices; and surface energy fluxes (using Bowen ratio and eddy correlation techniques). The intensive airborne and ground campaigns were coordinated with Landsat overpasses in February, May, and September.

These data are providing spatially-distributed information on important variables such as surface soil moisture, albedo, absorbed photosynthetically active radiation, and evaporation. The aim is to develop simulation models that capture the essential physical

"We need to understand how deserts process solar energy to under-stand desertification."
—Kris Havstad

processes of energy and carbon balances for this heterogeneous landscape. Preliminary data were reported in June at the Second International Airborne Remote Sensing Conference and Exposition in San Francisco.

This project has been funded by the USDA/ARS Global Change research program. Additional funds have been received for 1997–98 to expand the project to a cross-site comparison with campaigns planned for the Sevilleta and Central Plains LTER sites.

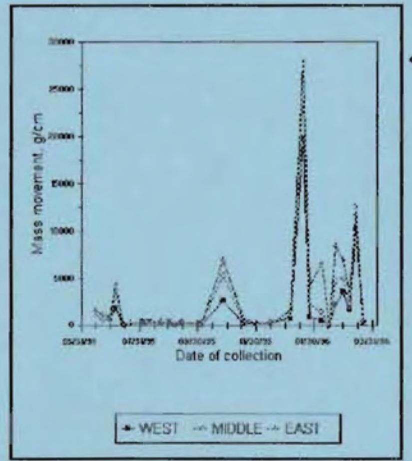
Contributed by Kris Havstad, USDA/ARS, Jornada Experimental Range

Winter Dust Storm

(Continued from page 1)

of these shrubs. Much of the material captured in the dunes may arrive during short periods of high wind velocity, particularly during periods of drought.

Gillette, who is a member of the NOAA's Fluid Modeling Facility in Research Triangle Park, North Carolina, brings his career-long expertise in wind-erosion studies to the Jornada LTER program. His station for monitoring wind erosion is located in a central position in the Jornada basin. It includes several meteorological towers, with instruments to record wind speeds, wind direction, and particle saltation. Collections of captured dusts will be analyzed for mineralogy as a means of tracing the origin of wind-borne materials and their contributions to soils in the region. His efforts will provide a valuable long-term dataset for wind erosion at the Jornada LTER site.



Dust transport in the Jornada Basin during 1995 and 1996

ESA Annual Meeting

(Continued from page 1)

clined significantly when summer rains failed to materialize for several years. Based on the results of these various studies, it will be important to examine the historical monthly records of rainfall at the Jornada to calculate the annual growth of grasses and shrubs in computer simulation models of vegetation changes in the basin.

Featured Investigator

Curtis Monger of NMSU's Agronomy Dept.

This issue of *Jornada Trails* recognizes the contributions of Dr. Curtis Monger to the Jornada LTER program. Curtis is an associate professor of pedology in the Department of Agronomy at New Mexico State University. Over the past ten years he has maintained an active program of research to understand the origin and development of arid land soils in southern New Mexico. Recently, working with a graduate student, Arnulfo Rojas, Curtis provided a detailed soil map for the alluvial slopes of Mt. Summerford, encompassing the area of the original LTER transects.

Curtis's work shows an enormous diversity of soils and landscapes in the Jornada Basin. Alluvial soils at the foot of Mt. Summerford are Holocene, with radiocarbon ages of about 3000 years before present. In contrast, in the central basin, ancient floodplain deposits left by the Rio Grande date to 1.6 million years ago, based on argon isotope analysis. Working with Greg Mack and others, Curtis recently produced a short classroom video —aimed at an advanced high school or early college audience—describing the varied geologic history of the entire Rio Grande Valley near Las Cruces.

Curtis Monger

Curtis has just received $79,865 from the USDA Competitive Grants program to supplement his efforts in the LTER program. Specifically, he will examine the dynamics of grassland ecosystems during the Holocene by examining the $\delta^{13}C$ signature left in soil carbonates of the Jornada basin. The Jornada LTER team is certainly pleased to have the expertise and productive collegiality of Curtis Monger as part of its program.

JORNADA TRAILS

Jornada LTER Program
The Phytotron
Duke University
Durham, NC 27708

JORNADA TRAILS

Jornada Long-Term Ecological Research Program

Volume 3 Issue 1, March 1997

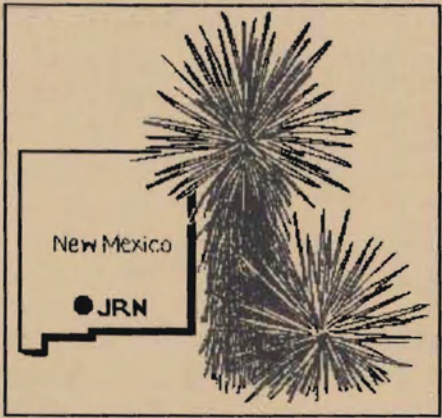
Where Are They Now?

Since 1991 the Jornada has been host to a large number of undergraduate students who have conducted field investigations as part of the Research Experience for Undergraduates (REU) program sponsored by the National Science Foundation.

Their projects have ranged from studies of the seed bank of desert annuals to examinations of runoff and erosion from desert soils. Several students working with Peter Herman of New Mexico State University have been coauthors of one or more papers published in *Applied and Environmental Microbiology* that describe aspects of microbial ecology in Chihuahuan desert soils.

An examination of the fate of 20 REU students trained at the Jornada from 1991 to 1996

Over the six-year period, a total of twenty REU students have come from four universities around the U.S., and they have worked with eleven different advisors during their field seasons at the Jornada.



The Jornada LTER Program is an NSF-funded project.

Jornada Trails polled the students' advisors to ask what has become of the students in our REU program, and the responses are gratifying:

- Seven students now pursue graduate degrees or careers in environmental science.
- Five have pursued other degrees or employment—all in some aspect of science or engineering.
- Three are still in school.
- Five have an unknown fate.

We believe that NSF should be encouraged that more one-third of our REU students have continued in some aspect of environmental science.

Beginning in 1996, an additional REU program, cooperative between

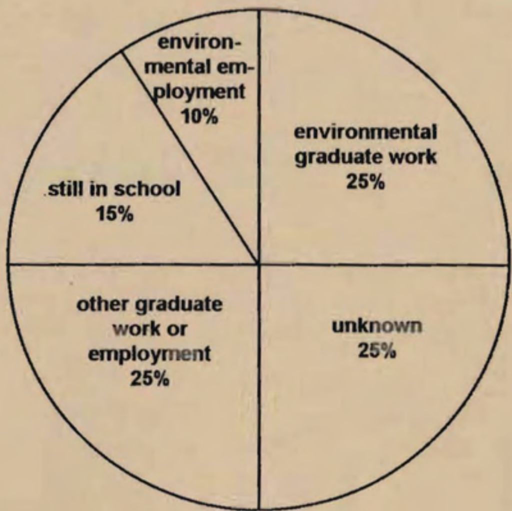
(Continued on page 2)

Reynolds Receives Two Grants to Foster International Comparisons to the Jornada LTER

James F. Reynolds (Duke University) has recently received two grants to compare research findings at the Jornada to other, similar desert sites around the world.

Reynolds received \$105,000 from the Carnegie Mellon Center for Integrated Studies of the Human Dimensions of Global Change to allow

(Continued on page 2)



REU Students of the Jornada, 1991–1996

inside...

July 10, 1997

Friends of the Jornada Symposium

Be sure to register for the annual Friends of the Jornada Symposium to be held at New Mexico State University on Thursday, July 10, 1997. A full day of informal research presentations will be followed by an evening barbeque at the USDA Headquarters Ranch.

This is the Seventh Annual Symposium, and we expect that it will continue to provide a lively exchange of ideas and data on the Chihuahuan desert environment. Optional field trips to visit individual research sites are available on the following day.

For information contact: Kris Havstad, USDA/ARS Jornada Experimental Range, Box 3JER, New Mexico State University, Las Cruces, N.M., 88003

August 9, 1997

Pre-ESA Jornada Field Trip

As part of the Annual Meeting of the Ecological Society of America, the Society will sponsor a field tour of USDA and LTER research at the Jornada. The trip will be held Saturday, August 9, 1997—one day before formal registration for the ESA meeting in Albuquerque. Among various studies, participants will see how the LTER provides long-term records of net primary productivity, grazing impact, wind erosion and dust deposition.

If you are interested in participating, please consult the April 1997 issue of the *Bulletin of the Ecological Society of America* for details of registration and logistics.

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Where Are They Now?

(Continued from page 1)

Howard University in Washington D.C. and New Mexico State University, began with the goal of bringing ethnically and culturally diverse students to the field environment of the Chihuahuan desert. After a few weeks at the Jornada, all students travel to Washington, D.C., to see how government agencies determine our country's environmental policy.

Also funded by the National Science Foundation, this REU program enrolled nine students in 1996, and a similar number is expected in the coming year.

Reynolds

(Continued from page 1)

comparative, modeling studies of semi-arid ecosystems in the Karoo of South Africa, in the arid rangelands of Australia, in the Monte scrublands in Argentina, and in the grasslands at the Jornada.

Separately, Reynolds received \$85,000 as part of the initial set of awards from the Inter-American Institute (IAI) for Global Change Research. The IAI grant will support a graduate student at Duke who will develop a quantitative estimate of changes in the water balance of rangelands that have experienced desertification.

With an eye toward the importance of biodiversity, this research will focus on whether cattle selectively feed on species with higher realized growth rates and therefore greater uptake and transpiration of soil water.

Recent Publications from the Jornada

Anderson, D. M., R. E. Estell, **K. M. Havstad**, W. L. Shupe, R. Libeau and L. W. Murray. 1996. Differences in ewe and wether behavior when bonded to cattle. *Applied Animal Behavior Science* 47: 201-209.

Anderson, D. M., P. Nachman, R. E. Estell, T. Ruckgauer, **K. M. Havstad**, E. L. Fredrickson and L.W. Murray. 1996. The potential of laser-induced fluorescence (LIF) spectra of sheep feces to determine diet botanic composition. *Small Ruminant Research* 21: 1-10.

Fredrickson, E. L., J. R. Barrow, J. E. Herrick, **K. M. Havstad**, and B. Longland. 1996. Low cost seeding practices for desert environments. *Restoration and Management Notes* 14: 72-73.

Fredrickson, E. L., R. E. Estell, **K. M. Havstad**, T. Ksiksi, J. Van Tol, and M. D. Remmenga. 1996. Effects of ruminant digestion on germination of Lehmann lovegrass seed. *Journal of Range Management* 50: 20-26.

Ho, M., R. E. Roisman, and **R. A. Virginia**. 1996. Using strontium and rubidum tracers to characterize nutrient uptake patterns in creosotebush and mesquite. *Southwestern Naturalist* 41: 239-247.

Huenneke, L. F. 1997. Outlook for plant invasions: Interactions with other agents of global change. Pp. 95-103. In J. O. Luken and J. W. Thieret (eds.). *Assessment and Management of Plant Invasions*. Springer-Verlag, New York.

Huenneke, L. F. and I. R. Noble. 1996. Ecosystem function of biodiversity in arid ecosystems. Pp. 99-128. In H. A. Mooney, J.H. Cushman, E. Medina, O. E. Sala and E.-D. Schulze (eds.). *Functional Roles of Biodiversity: A Global Perspective*. John Wiley and Sons, New York.

Kemp, P. R., **J. F. Reynolds**, Y. Pachepsky, and J.-L. Chen. 1997. A comparative modeling study of soil water dynamics in a desert ecosystem. Water Resources Research 33: 73-90.

Li, H. and **J. F. Reynolds**. 1997. Modeling effects of spatial pattern, drought, and grazing on rates of rangeland degradation: A combined Markov and cellular automaton approach. Pp. 211-230. In D. A. Quattrochi and M. F. Goodchild (eds.). *Scale in Remote Sensing and GIS*. Lewis Publishers, Boca Raton, Florida.

Richie, J. C., A. Rango, W. P. Kustas, T. J. Schmugge, K. Brubaker, X. Zhan, **K. M. Havstad**, B. Nolan, J. H. Prueger, J. H. Everitt, M. R. Davis, F. R. Schiebe, J. D. Ross, K. S. Humes, L. E. Hipp, K. Ramalingam, M. Menenti, W. G. M. Bastiaanssen, and H. Pelgrum. 1996. JORNEX: An airborne campaign to quantify rangeland vegetation change and plant community-atmospheric interactions. Pp. 54-66. In *The Proceedings of the Second International Airborne Remote Sensing Conference and Exposition*. San Francisco, Ca.

Book Review

A Valuable Addition to the Desert Ecologist's Library

Ecological Communities and Processes in the Mojave Desert Ecosystem, Rock Valley, Nevada, by P. W. Rundel and A. C. Gibson. Cambridge, 386 pp., illus., \$100

Rundel and Gibson provide a broad overview of plant and animal ecology in the Mojave Desert. Separate chapters deal with perennial and annual plants, and with mammals, reptiles, birds, arthropods and soil organisms. Adaptations of Mojave Desert plants and animals are treated at length, and nitrogen cycling also receives extended treatment. The book concludes with a discussion of human impacts on Mojave Desert ecosystems.

While generally applicable to much of the Mojave Desert, the main data on which the book relies were collected over many years from studies at Rock Valley, located in the Nevada Test Site. Rock Valley was chosen as a validation site under the International Biological Program (IBP), and the authors argue that it is one of the best studied warm desert sites in the world.

A colleague loaned me the book for perusal one afternoon, and I found it hard to put down that evening. The geologist, the biologist, the ecologist, and the soil scientist will all find much fascinating information in these pages—but be prepared for the hefty price tag.

—*Peter K. Haff, Division of Earth Sciences, The Nicholas School of the Environment, Duke University*

Featured Investigator

Kris Havstad

Jornada Trails is pleased to recognize Kris Havstad as its featured investigator. Arriving in Las Cruces from Montana State University, Kris assumed the position of Supervisory Range Scientist for the USDA's 78,000-ha Jornada Experimental Range in 1988. He immediately fostered a productive collaboration with the LTER program that has flourished for the last decade. All who visit the Jornada appreciate his keen insight into the natural history of the desert and his quiet humor on the daily activities associated with cattle ranching.

Trained in range science at Oregon State (B.S.), New Mexico State (M.S.) and Utah State (Ph.D.) Universities, Kris has focused his research on the diet selection of rangeland animals. A variety of his papers have shown how animals learn and respond to the differences in plant tissue chemistry that determine food preferences.


Kris Havstad

At Montana State, Kris worked on methods for controlling noxious weeds using livestock rather than costly herbicides. Before leaving Montana, Kris had been promoted to Associate Professor, also receiving MSU's Award of Excellence and the citation "Range-man of the Year" from the Montana Association of Conservation Districts.

Kris is a rich source of ideas that he shares in cooperative research with USDA and LTER personnel. He is the driving force behind our recent large-scale replicated experiments to examine the effects of intense cattle grazing at different seasons on the ecology of the grass-shrub transition in New Mexico. He has also worked closely with the effort by the U.S. National Academy of Science to "rescue" certain early data gathered at the Jornada and stored field notes that were beginning to deteriorate. These priceless records of vegetation cover from early in the century represent the essence of long-term ecological research.

Recognized in 1995 by the Outstanding Achievement Award given by the Society for Range Management, Kris Havstad has been an outstanding and crucial addition to the LTER program at the Jornada.

JORNADA TRAILS

Jornada LTER Program
The Phytotron
Duke University
Durham, NC 27708

Participation of LTER investigators in cross-site research activities, 15 October 1994 -- present

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We have engaged in a variety of studies to compare ecological processes in the Jornada Basin to other arid and semiarid ecosystems of North America. In studies of soil spatial pattern (see tab "Core Area 3"), we used geostatistics to compare the distribution of soil nutrients at the Jornada, Sevilleta, and Central Plains LTER sites and at additional sites located in the Mojave Desert of California and the Great Basin Desert of Nevada (Schlesinger et al. 1996).

In addition, several graduate students are comparing the biology of Bouteloua grasses along the North-South gradient semiarid ecosystems represented by the Central Plains, Sevilleta and Jornada LTER sites. David Lightfoot (UMN) has obtained ancillary NSF funding to replicate his small mammal exclusion experiment at the Jornada, Sevilleta and Mapimi Biosphere Reserve sites, extending nearly the full length of the Chihuahuan desert.

In 1995, Agricultural Research Service scientists began a series of remote sensing campaigns designed to link point-scale studies to large area processes and to evaluate the energy and water fluxes at the Jornada Experimental Range. This project (titled the JORNada EXperiment, or JORNEX) focused on black grama grassland, mesquite duneland, and the transitional zone between these two communities. During five campaigns over two years, conventional vegetation and micrometeorological measurements were used to supplement ground-, airborne- and satellite-based remote sensing measurements to develop algorithims to estimate landscape-scale energy flux.

In 1997, this original program was expanded to field test EOS instruments such as MODIS, ASTER, and MISR, and to include the Sevilleta LTER site. In May, 1997, scientists from at least 20 agencies conducted validation tests for various EOS instruments on JORNEX sites, and original JORNEX ground-, airborne-, and satellite-based measurements were conducted on desert grassland sites at the Sevilleta. Simultaneously, AVIRIS, Landsat TM and TIMS data were acquired at both the Jornada and Sevilleta LTER sites in May and June 1997. This intensive campaign was titled PROtotype Validation Exercise, or PROVE.Further JORNEX campaigns are planned for 1998.

Thus, our cross-site and regionalization efforts, both within and outside the LTER network, attempt to compare the Jornada Basin to the main semiarid/arid transition in North America (east-west) and the Chihuahuan desert gradient that extends into Central America.

The following are workshops attended by Jornada LTER investigators to foster cross-site and comparative studies between the Jornada Basin and other sites of interest:

January 1995	Reynolds, Virginia, Huenneke attended a meeting at the Sevilleta to develop a cross-site experiment (with SEV and CPER) examining grama grasslands in arid and semiarid environments
June 1995	Huenneke was an invited member of the arid lands working group at a workshop of the Americas Interhemisphere Geo-Biosphere Organization (AMIGO), Stanford, California
March 1996	Daryl Moorhead (Texas Tech) represented the Jornada at the LIDET (Longterm Decomposition Experiment Team Workshop), in Belen, N.M. (SEV LTER Site)
June 1996	Huenneke represented the Jornada at the international workshop "Scenarios of Future Biodiversity: Causes, Patterns, and Consequences," held at the National Center for Ecological Synthesis and Analysis and cosponsored by the Interamerican Institute (IAI) for Global Change Research and the IGBP Program on Global Change and Terrestrial Ecosystems (GCTE).
September 1996	Herrick (USDA) represented the Jornada at the LTER workshop "Comparative Patterns of Productivity and Species Diversity," held at the National Center for Ecological Research and Analysis, Santa Barbara, California.
November 1996	Reynolds participated in the Science-on-Line Antarctica (SOLA) Workshop for the McMurdo Dry Valley LTER Site to aid in the planning of database and geographic information systems to support a Dry Valleys model. Granlibakken (Lake Tahoe), California.
January 1997	Lightfoot represented the Jornada at part one of the US/Mexico International LTER workshop at Puerto Vallarta, Mexico.
April 1997	Huenneke represented the Jornada at the part two of the US/Mexico International LTER workshop at the Sevilleta Field Station.

Participation by Jornada investigators in LTER Network activities
15 October 1994 -- present

October 1994	Schlesinger attended LTER-CC Meeting Dillard, Georgia (CWT LTER Site)
April 1995	Havstad represented the Jornada at the LTER-CC Meeting, Norfolk, Virginia (VCR Site)
August 1995	Nolen (GIS Specialist) and LaFleur (Data Manager) attended LTER Data Manager's Workshop, Snowbird, Utah.
October 1995	Huenneke represented the Jornada at the LTER CC meeting, Cedar Creek, Minnesota (CDR Site)
March 1996	Curtis Monger represented the Jornada at the LTER Network Workshop on Soil Methods Standardization, Belen, N.M. (SEV site).
April 1996	Huenneke represented the Jornada at the LTER CC meeting, Konza Prairie, Kansas (KNZ Site)
October 1996	Virginia represented the Jornada at the Autumn LTER-CC Meeting, Harvard Forest, Petersham, MA. (HFR site).
October 1996	Anderson (Acting Data Manager) attended LTER Information Managers' Workshop, Archibold Research Station, Florida
April 1997	Huenneke represented the Jornada at the Spring CC meeting of the LTER Network, H.J. Andrews Experimental Forest, Oregon (AND Site)
June 1997	Reynolds represented the Jornada at a workshop of the Department of Defense, Strategic Environmental Research and Development Program, "Management-scale Ecological Research," Warrenton, Virginia

From the Old West to the Digital Age

Chihuahuan Desert Rangeland Research Center

Established in 1927 to conduct "educational, demonstrative, and experimental development with livestock, grazing methods and range forage."

New Mexico State University

College of Agriculture and Home Economics
Department of Animal & Range Sciences
Box 30003, Dept. 31 / Las Cruces, NM 88003
(505) 646-2514

History

Early hunting and gathering societies, part of the Jornada Mogollon culture, first roamed this area. Later, various Apache tribes made these lands their home. An eight-mile stretch of the Camino Real, the route established by the Spanish between Chihuahua, Mexico and Santa Fe, crossed the northern part of the Center. In 1887, the first Homestead was filed with the U.S. government for property now included in the Center.

Several ranchers owned various portions of the land now constituting the Center, but in 1925 Max Vanderstucken, who then owned the land, was facing foreclosure and spoke to J. L. Lantow, head of the animal husbandry department at New Mexico A&M. He recommended the College buy his ranch, and in February 1926 the College acquired his land, with grazing rights on adjoining public lands. In 1927, Congress granted the public lands to the College for research purposes. The last parcel was acquired in 1984 through a "land swap" between the federal government and the State of New Mexico.

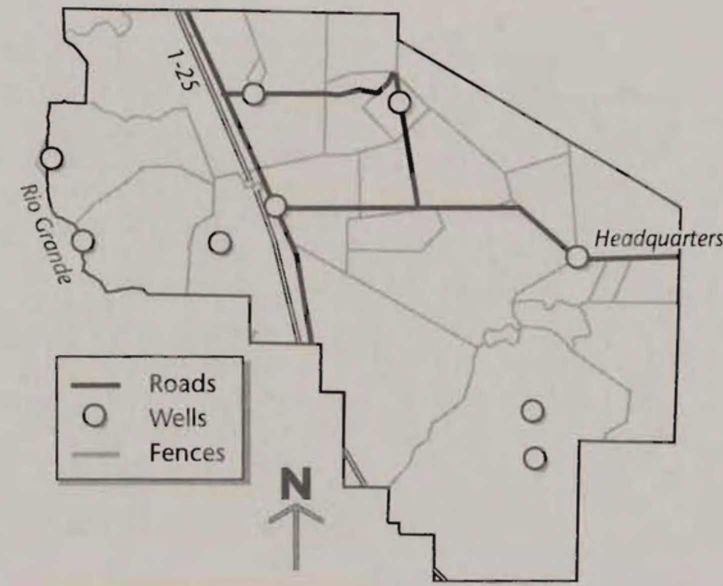
Location and Description

The Center is located in Doña Ana County, New Mexico, at the southern end of the Jornada Plain. Now divided by Interstate 25, the Center encompasses almost 100 square miles, with one-fourth of the land west of the interstate.

LAND on the Center varies widely, with elevations from 4,000 ft on the Rio Grande flood plain on the west side to 5,840 ft at the top of Summerford Mountain in the Doña Ana Mountains on the east side. The nearly level plains of the north and central parts of the Centrer are on the Jornada del Muerto basin, with several small playa areas where water collects after rainfall. Soils range from sandy loams to clays overlying caliche hardpan.

Several VEGETATION TYPES occur on the center. Creosotebush dominates the upper slopes of the mountains and the hills along the river. At lower elevations, the creosotebush type grades into the mesquite type that grows on sandier soils, and into the tarbush type on heavier soils. The plains area, once dominated by black grama, today has been invaded by mesquite. These mesquite stands are interspersed with snakeweed and many species of grasses and forbs.

WILDLIFE POPULATIONS on the Center are rich and varied. Among the larger mammals are mule deer, pronghorn antelope, gemsbok, bobcat, coyote, badger, and fox. Mountain lions have been sighted. There are also many rabbit and rodent species. Several bird species migrate through the area, but a large number also live and nest on the rangeland. Species such as roadrunners, hawks, and occasionally golden eagles are seen on the Center. Numerous lizard and snake species also inhabit these lands.



Research

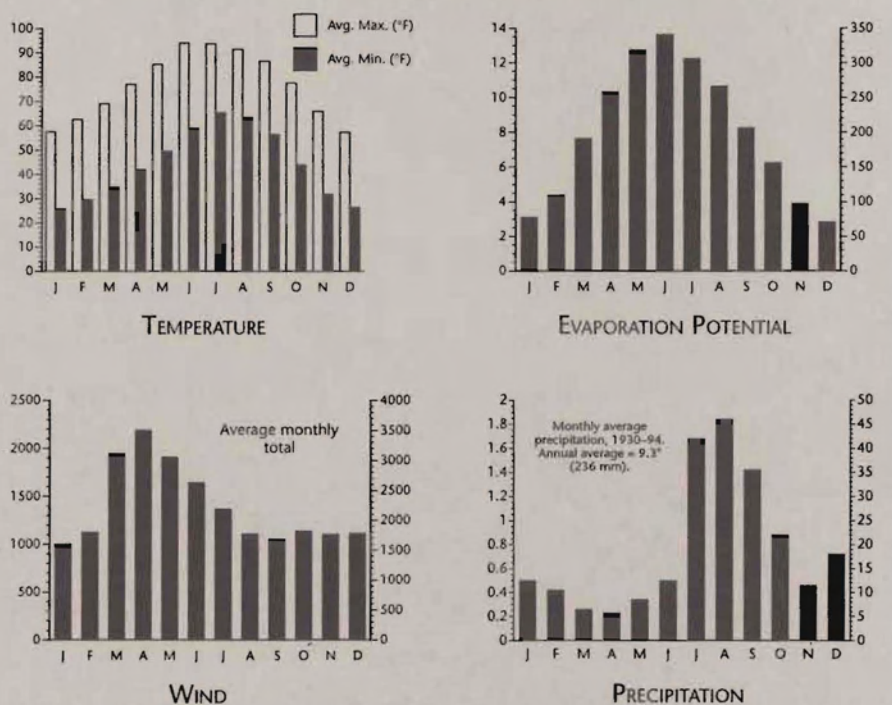
Early studies included inventorying plants, brush control, and attempts at reseeding to improve forage conditions. Early livestock studies focused on supplemental feeding during drought, as well as practices to improve herd management.

Current research efforts include—

- Evaluating continuous and seasonal grazing strategies at different intensities to determine effects on livestock performance as well as plant cover and composition.
- Evaluating performance of breeds of cattle in relation to quality and quantity of forage in a hot, arid environment.
- Determining whether Angora and Spanish goats can affect shrub dominance.
- Determining the influence of range conditions on wildlife populations.
- Autecology of plant species.
- Assessing competition and other interactions between common plant species.
- Ascertaining the role of small herbivores in a desert environment.

In addition to research conducted by the Department of Animal and Range Sciences, faculty and graduate students from other NMSU departments are conducting research on the Center. Currently much of the research is in conjunction with the Long Term Ecological Research program, which is part of a nationwide program funded by the National Science Foundation.

The Center's Environmental Characteristics



A rich heritage: Looking south toward the Doña Ana Mountains, ca. 1940. The dark area at the base of the mountains was dominated by shrubs.

The Jornada Experimental Range Las Cruces, New Mexico

A Laboratory Without Walls

Agricultural Research Service

Agricultural Research Service

The Agricultural Research Service (ARS) is the primary research agency of the U.S. Department of Agriculture. Research programs are planned and carried out in light of national priorities with the cooperation and advice of Congress, U.S. industry, state agricultural experiment stations and universities, USDA action agencies, and other organizations and institutions interested in the future of U.S. agriculture.

ARS mission is to:
Develop new knowledge and technology needed to solve technical agricultural problems of broad scope and high national priority in order to ensure adequate production of high quality food, fiber, and other agricultural products to meet the institutional needs of the American consumer, to sustain a viable food and agricultural economy, and to maintain a quality environment and natural resource base.

ARS conducts research on animal and plant production; protection of animals and plants from diseases; use and improvement of soil, water, and air resources; processing, storage, and food safety; and human nutrition.

At present, ARS has over 100 locations strategically located across major farm and rangeland ecosystems and climate zones of the United States. Consequently, ARS has the ability to bring research expertise to bear on the same national problems in several different geographic locations.

Jornada Experimental Range mission is to:
Develop new knowledge of ecosystem processes as a bases for management and remediation of desert rangelands.

The Jornada Experimental Range has the largest acreage of any ARS field station. It is located in the Southern Plains Area, a subunit of ARS, that is headquartered at College Station, Texas.

Visitors and Information
Visitors are most welcome at the Jornada Experimental Range. For information or tours, contact:

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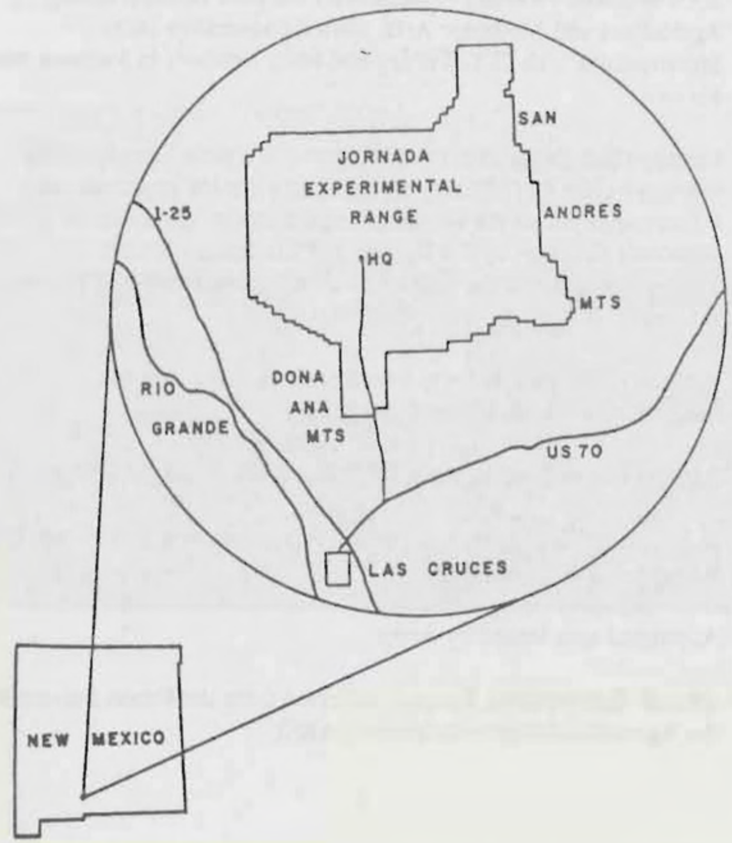
The Jornada Experimental Range Las Cruces, New Mexico

Location

The Jornada Experimental Range is located 23 miles (37 kilometers) north of Las Cruces. Most of the Experimental Range is on the Jornada del Muerto Plain, which lies between the Rio Grande Valley on the west and the San Andres Mountains on the east. The crest of the San Andres Mountains roughly coincides with the eastern boundary of the Range.



Historical Highlights

1598 Don Juan de Oñate followed the Rio Grande northward during his conquest and settlement of New Mexico. During the next three centuries, the Jornada del Muerto (Journey of Death) Plain was traversed by mission supply caravans, the Santa Fe-Chihuahuan trade caravans and, finally, stagecoach lines. This trail is still visible a few miles west of the Jornada Experimental Range.

1858 First land survey of the area which later formed the Jornada Experimental Range, with records made of soils and vegetation.

1880 Beginning of a decade during which ranches were established at springs in the San Andres Mountains.

1901 C.T. Turney, a rancher, settled at site of present-day Jornada Headquarters and gained control of water sources in the area.

1904 E.O. Wooton, visionary botanist with the New Mexico College of Agriculture and Mechanic Arts, started cooperative range investigations with C.T. Turney and other ranchers in southern New Mexico.

1912 Largely through the efforts of Wooton, the Public Domain lands comprising the C.T. Turney ranch were set aside by Presidential Executive Order as the Jornada Range Reserve, administered under Wooton's direction by the Bureau of Plant Industry within the USDA. Turney remained as the first of a continuing succession of cooperating ranchers.

1915 Jornada Range Reserve was transferred from the Bureau of Plant Industry to the U.S. Forest Service.

1927 Jornada Range Reserve renamed Jornada Experimental Range.

1945 U.S. Army leased mountain portion of Jornada as a buffer zone for White Sands Missile Range.

1953 Additional area leased by Army.

1954 Jornada Experimental Range transferred from the Forest Service to the Agricultural Research Service (ARS).

1971 Research and grazing use reinstated on part of the Army-controlled portion of the Jornada Experimental Range.

1977 Selected as a Biosphere Reserve by UNESCO's Man and the Biosphere Program. Also, designated as an Ecological Reserve by The Institute of Ecology.

1983 Domestic sheep introduced on the Jornada Experimental Range.

1984 Cooperative rancher arrangement discontinued, and all livestock purchased and managed by Experimental Range staff as property of the State of New Mexico.

1989 Included as one of eighteen sites of the National Science Foundation's network for long-term ecological research in the United States.

1994 Cooperative agreement (labeled the Ecosystem Stewardship Project) established with Beck Land and Cattle Company to manage livestock production in Pastures 1A and 1B within a holistic framework.

Present Research Activities

Our research emphasis on rangeland management continues the original focus of the Jornada Experimental Range that began in 1912 (see page 20), but with an increased emphasis on understanding basic ecological processes in desert environments. Our core research program has four principle objectives:

1. ***Determine effects of stressors upon ecosystem processes.*** Understanding impacts of various stressors or perturbations, including human activities, is crucial to development of appropriate management practices. We want to identify indicators that can be incorporated into technologies to monitor and assess resource conditions. This research is being conducted in cooperation with scientists and staff of the Environmental Protection Agency (EPA) as part of their Environmental Monitoring and Assessment Program (EMAP).

2. ***Develop new knowledge to enhance survival and dispersal of native plants used for remediation of degraded rangeland.*** Plants in arid environments are challenged in acquiring sufficient water and nutrients for growth. Traditional methods for revegetation are generally economically and ecologically unsuccessful in this harsh environment. We want to develop affordable technologies for remediation that utilize natural processes to promote plant dispersal, establishment, and reproduction. Basic ecological processes that enhance plant survival by supplying essential nutrients and water during stressful periods are also studied.

3. ***Identify chemical attributes of shrubs which contribute to their landscape dominance.*** Plants, including shrubs such as creosotebush and tarbush, maintain chemical-based defenses which provide substantial competitive advantages in desert environments. We are examining the chemical basis of plant-animal and plant-environment interactions to learn how to manage arid rangelands either dominated by or with an increasing presence of these plants. In addition, we are looking for chemical components which may have value for medicinal or industrial uses.

4. ***Create innovative methods that manipulate livestock foraging and associated behaviors.*** Domestic livestock learn to forage. However, manipulating principles of social organization have been applied in only a limited fashion to livestock production systems. Our research focuses on developing practical technologies to manipulate animals based on principles governing group and individual behavior. Our goal is to affect animal distribution to more effectively manipulate forage utilization under extensive rangeland conditions.

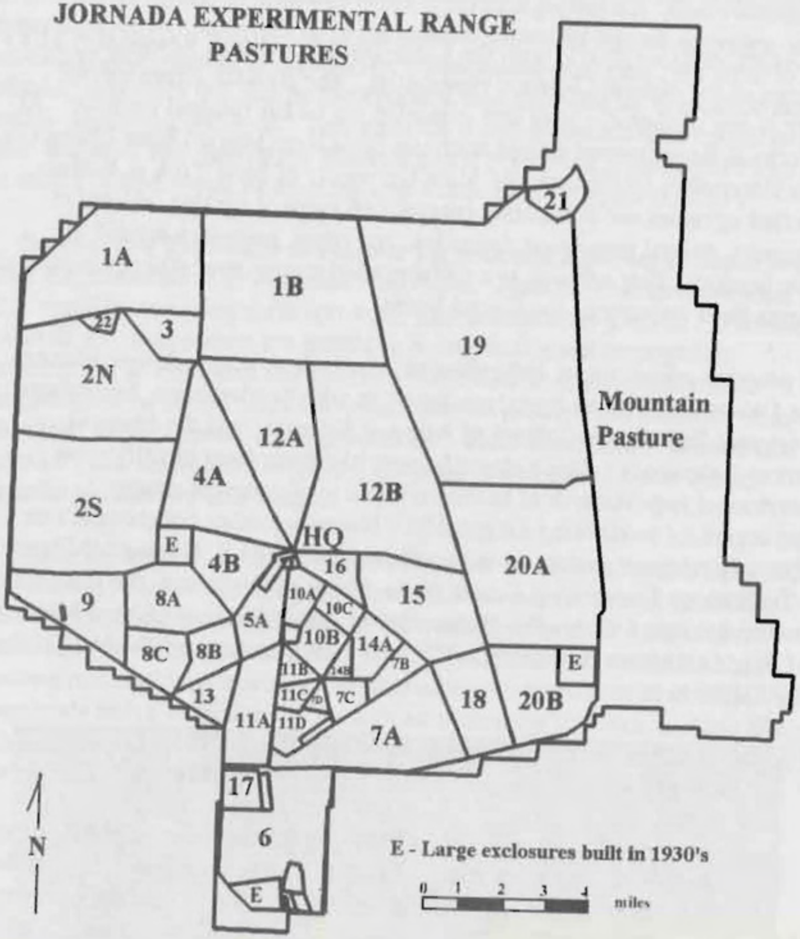
Collaborative Research

To fully utilize the scientific resources of the Jornada Experimental Range our research program is built on strong collaborations with other agencies and institutions with interest in the use and mangement of desert rangelands. A key example is our formal arrangement with EPA's Las Vegas, NV, laboratory to house scientists and staff for our cooperative research on environmental monitoring.

Our central collaboration is with the Long-Term Ecological Research (LTER) program of the National Science Foundation. The Jornada Experimental Range is one of eighteen sites that comprise the LTER national network. At the Jornada Experimental Range scientists from New Mexico State University, Duke University, Dartmouth, the State University of New York at Buffalo, and other agencies are conducting research on nutrient cycling, effects of consumers, animal population dynamics, and other processes related to desertification. This network is a collaboration among over 600 scientists and students from throughout the United States.

Our program compliments and enhances research activities at New Mexico State University, and we directly collaborate with faculty in the Agricultural Experiment Station, the College of Arts and Sciences, and the Physical Sciences Laboratory. These scientific activities span from identification of nutritional requirements of heifer calves to application of unique technologies for monitoring rangelands. Numerous other collaborators on studies of ecological processes in deserts include the U.S. Geological Survey, the Technology Engineering Center of the Corps of Engineers, the National Oceanographic and Atmospheric Association, the University of New Mexico, the Oregon Graduate Institute, the National Park Service, and the U.S. Fish and Wildlife Service.

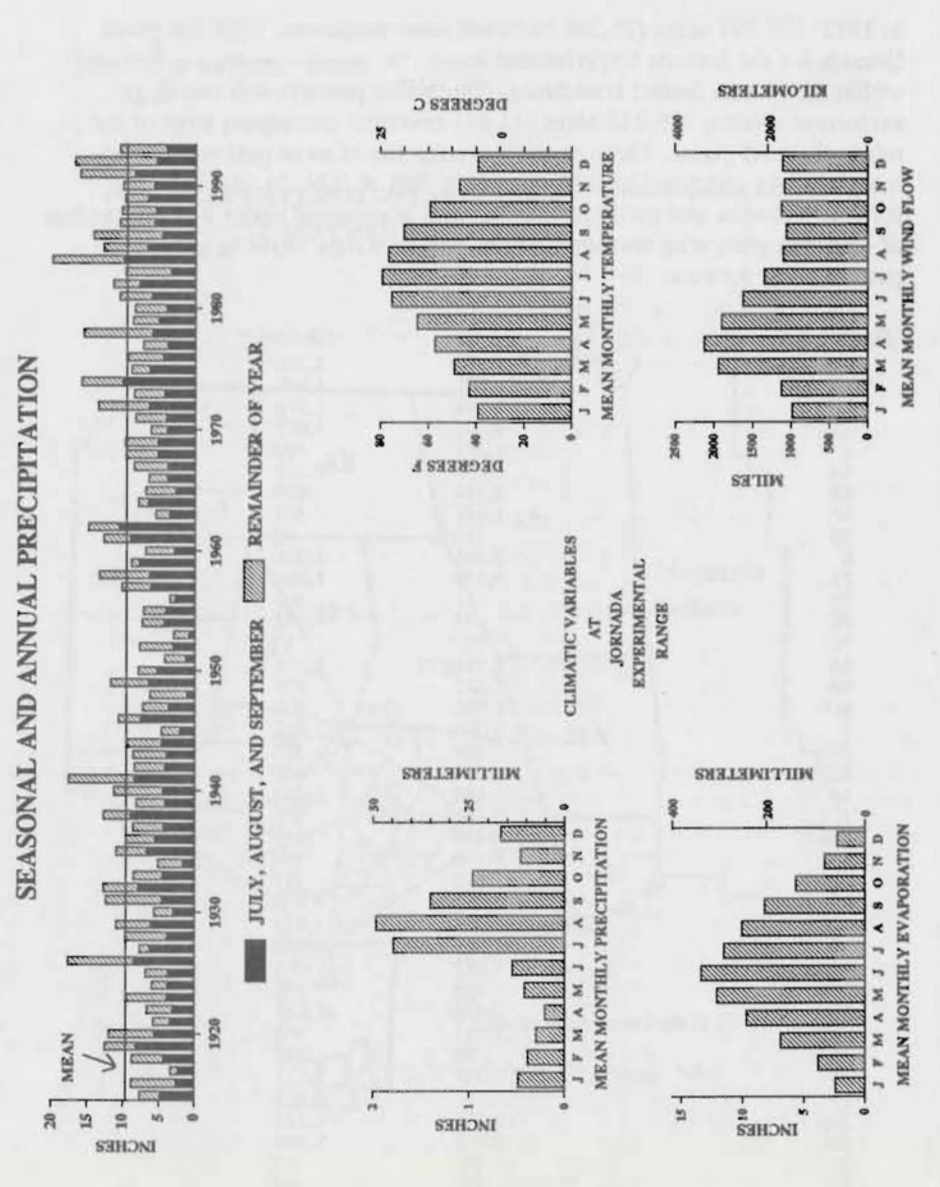
JORNADA EXPERIMENTAL RANGE PASTURES



Area

In 1912, 193,394 acres (78,266 hectares) were withdrawn from the Public Domain for the Jornada Experimental Range. A smaller acreage is included within the present fenced boundaries. Thirty-five pastures and two large exclosures totaling 105,238 acres (42,621 hectares) encompass most of the relatively level plains. These pastures are the site of most past and current research. An additional area (Pastures 19, 20A & 20B, 21, the Gravelly Ridges Exclosure and the Mountain Pasture) is managed under a Memorandum of Understanding with the White Sands Missile Range. Area in individual pastures is as follows:

Pasture No.	*Acres*	*Hectares*
1A	7,970	3,226
1B	11,863	4,802
2N	8,346	3,378
2S	9,591	3,882
3	1,384	560
4A	5,473	2,215
4B	2,151	870
5A	1,452	587
5B	182	73
6	5,084	2,058
7A	5,179	2,096
7B	741	300
7C	673	272
7D	217	87
8A	2,723	1,102
8B	1,232	498
8C	1,480	599
9	3,093	1,252
10A	804	325
10B	1,103	446
10C	648	262
11A	2,354	953
11B	459	185
11C	469	189
11D	823	333
12A	5,992	2,425
12B	10,905	4,414
13	1,012	409
14A	1,067	431
14B	326	131
15	4,483	1,814
16	1,151	465
17	730	295
18	2,547	1,031
19	24,277	9,828
20A	10,528	4,262
20B	3,439	1,388
21	828	335
22	251	101
Mountain Pasture	41,193	16,671
Dona Ana Exclosure	640	259
Gravelly Ridges Exclosure	640	259
Natural Revegetation Exclosure	640	259



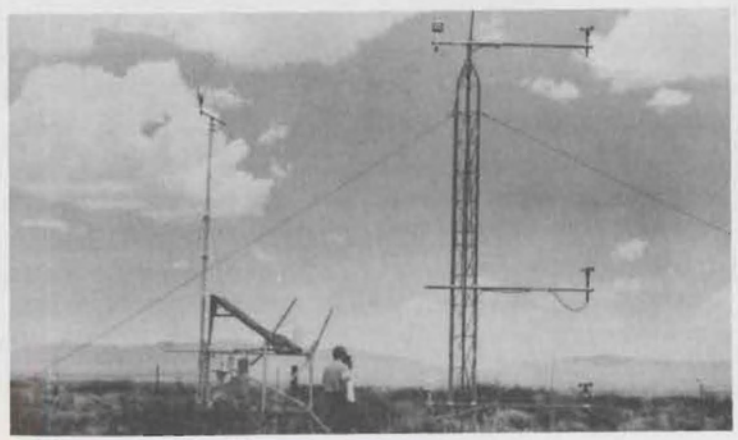
Climate

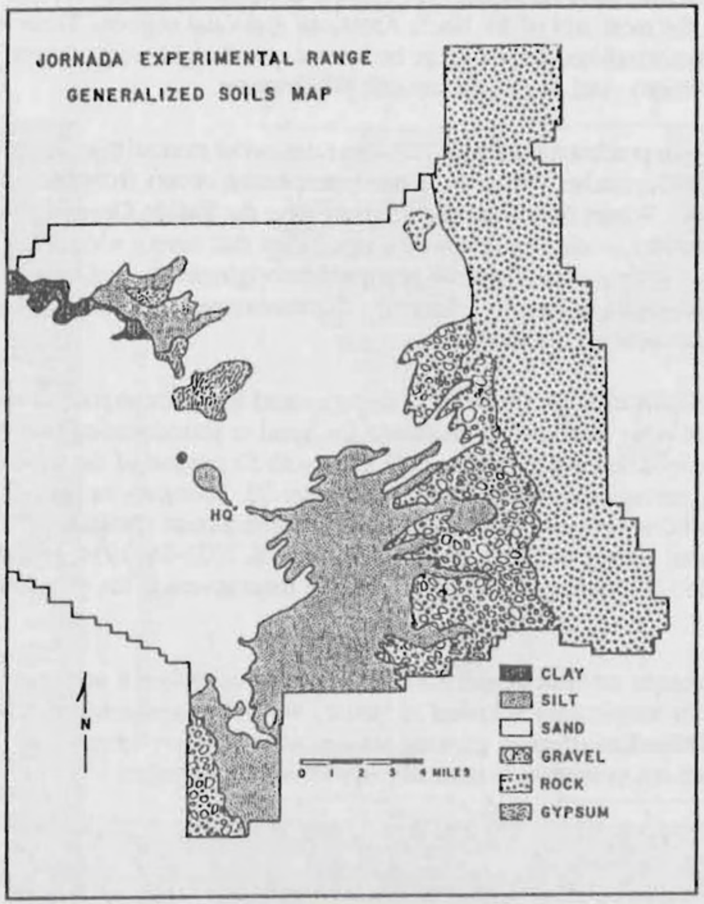
The Jornada Experimental Range lies within the Chihuahuan Desert, the largest desert in North America. The climate is typical of semidesert grassland, the most arid of the North American grassland regions. There is an abundance of sunshine, a wide range between day and night temperatures, low relative humidity, and extremely variable precipitation.

There are two precipitation peaks: summer rains occur primarily in July, August, and September; whereas, winter precipitation occurs from December to February. Winter frontal storms originate over the Pacific Ocean and are characterized by gentle, low-intensity precipitation that covers wide areas and may last for several days. Summer precipitation originates in the Gulf of Mexico and occurs as intense, convective thunderstorms that are highly localized and of short duration.

Rainfall records exist for the Jornada Experimental Range headquarters since 1915 and at other locations on the Range for equal or shorter timespans. Mean annual precipitation is 9.72 inches (247 mm) with 53 percent of the annual rainfall occurring between July 1 and September 30. Droughts, or periods of low rainfall that seriously injure vegetation, are a recurrent climatic phenomenon. Severe droughts occurred in 1916-18, 1921-26, 1934, and 1951-57. The 1951-57 drought is believed to be the most severe in the past 350 years.

Mean maximum ambient temperature is highest in June when it averages 97°F(36°C); temperature is lowest in January when the mean maximum is 56°F(13.3°C). The effective growing season, when both precipitation and temperature are favorable, is normally July through September.





Geology and Soils

Elevations range from 4,200 feet (1,260 meters) on the plains to 8,500 feet (2,833 meters) in the mountains. The San Andres Mountains were formed from a west-dipping fault block and have moderate to steep slopes on the west and precipitous slopes on the east. Rocks in the mountains were derived from marine sediments deposited during the Paleozoic.

Materials deposited by the ancestral Rio Grande and washed in from the surrounding mountains have formed the Jornada Plain, which occupies the level-to-gently-undulating floor of the intermountain basin. The basin is closed, with no external drainage, and water occasionally collects in the scattered low spots or playas. Coarser sediments are found near the foothills, and finer soil particles, the silts and clays, are found in the lowest areas. Both water and wind erosion processes are still active and microrelief changes are continuous.

Twenty-two different soil types are present on the Jornada Plain. These soils have almost no humus or organic matter, and there is little change in texture between surface soil and subsoil. Lime content is high in all soil types. Through time, lime from the soil and from calcareous dust has leached downward and deposited at the depth to which rainfall normally penetrates, from a few inches to several feet. This zone of lime accumulation, or caliche layer, is often so thick and dense that penetration by water or roots is severely limited.

Common Plants on the Jornada Experimental Range

Perennial Grasses:	
Black grama	*Bouteloua eriopoda*
Mesa dropseed	*Sporobolus flexuosus*
Red threeawn	*Aristida purpurea var. longiseta*
Wooton's threeawn	*Aristida pansa*
Tobosa	*Pleuraphis mutica*
Burrograss	*Scleropogon brevifolius*
Sand dropseed	*Sporobolus cryptandrus*
Alkali sacaton	*Sporobolus airoides*
Plains bristlegrass	*Setaria macrostachya*
Bush muhly	*Muhlenbergia porteri*
Fluffgrass	*Dasyochloa pulchella*
Annual Grasses:	
Six-weeks threeawn	*Aristida adscensionis*
Six-weeks grama	*Bouteloua barbata*
Needle grama	*Bouteloua aristidoides*
False buffalograss	*Munroa squarrosa*
Perennial Forbs:	
Desert baileya	*Baileya multiradiata*
Woolly paperflower	*Psilostrophe tagetina*
Leatherweed croton	*Croton pottsii*
Spiny-leaved perezia	*Perezia nana*
Annual Forbs:	
Tumbling russianthistle	*Salsola australis*
Wislizenus spectaclepod	*Dithyrea wislizenii*
Chinchweed	*Pectis papposa*
Shrubs and Shrublike Plants:	
Creosotebush	*Larrea tridentata*
Honey mesquite	*Prosopis glandulosa var.glandulosa*
Tarbush	*Flourensia cernua*
Broom snakewood	*Gutierrizia sarothrae*
Fourwing saltbush	*Atriplex canescens*
Soaptree yucca	*Yucca elata*
Longleaf ephedra	*Ephedra trifurca*
Whitethorn	*Acacia constricta*
Ocotillo	*Fouquieria splendens*
Wheeler sotol	*Dasylirion wheeleri*
Trees:	
Red-berry juniper	*Juniperus erythrocarpa*
Mexican pinyon pine	*Pinus cembroides*

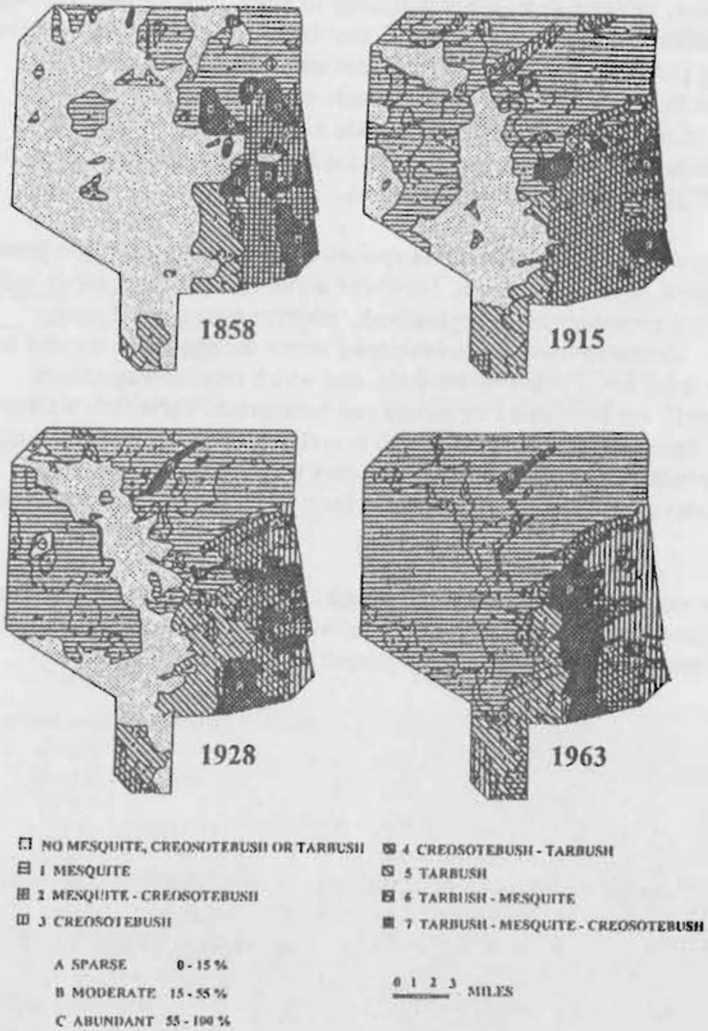
Nomenclature Sources: Kelly W. Allred, 1993, A Field Guide to the Grasses of New Mexico, and 1988, A Field Guide the Flora of the Jornada Plain (publications of the NM Agricultural Experiment Station).

Vegetation

The Jornada Experimental Range is usually classified as semidesert grassland, an ecosystem which covers about 26 million acres (10.5 million hectares) in southeastern Arizona, southern New Mexico, western Texas, and northern Mexico. Thus, research results are applicable to much larger areas. Although called "grassland", the region contains a complex of vegetation types ranging from nearly pure stands of grass, through savanna types with grass interspersed by shrubs or trees, to nearly pure stands of shrubs. The mountains, plains, and drainageways provide a great variety of habitats for plants, and the flora is rich in species. On the Experimental Range, some 545 species of higher plants have been collected.

On the Jornada Plain, the major grass species on sandy soils are black grama, mesa dropseed, and red threeawn. Shrubs or shrub-like plants on sandy soils include honey mesquite, fourwing saltbush, soaptree yucca, and broom snakeweed. Extensive dunes have developed where mesquite has invaded sandy soils. Low-lying areas with heavier soils, and which receive water from surface runoff, are dominated by tobosa and burrograss. Tarbush is a frequent invader of these heavy soils. Slopes with gravelly soils near the mountains are typically dominated by creosotebush. In years with favorable winter and spring moisture, many annual grasses and forbs are also abundant across soil types.

Within the mountains, shrub types are mixed. Major dominants include honey mesquite, creosotebush, sotol, ocotillo, and whitethorn. Some areas of scrub woodland are dominated by red-berry juniper and Mexican pinyon pine.



Major brush species by species composition classes on the Jornada Experimental Range.

Brush Invasion

The increase in brush on the Jornada Plain is well documented. A land survey made in 1858 included notes on soils and vegetation. From these notes, the relative abundance of brush types in 1858 was reconstructed. Extent of brush types was also determined from vegetative surveys made on the Jornada Plain in 1915, 1928, and 1963.

In 1858, good grass cover was present on more than 90 percent of the 144,475 acres (58,492 hectares) studied. By 1963, less than 25 percent of the area had good grass cover. The table below shows the percentage of area occupied by dense (55 to 100 percent of perennial plant composition) brush cover of the major shrubs at various dates.

Vegetation Cover[1]	1858	1915	1928	1963
	- - - - - - - -	Percent	- - - - - - - -	
Brush-free	58	25	23	0
Honey mesquite	5	24	22	50
Creosotebush	0	3	5	14
Tarbush	0	2	5	9

[1] *Dense cover ≥ 55% of perennial plant composition.*

Mesquite is the primary invader on sandy soils. Tarbush has increased on the heavier soils, and creosotebush occupies shallow and gravelly soils. Collectively, the spread of brush has been ubiquitous and rapid. As a result, range carrying capacities have been drastically lowered. Periodic droughts, unmanaged livestock grazing, and brush seed dispersal by humans, livestock, and rodents have all contributed to the spread of the shrubs. Brush has increased in permanent livestock exclosures erected during the 1930's, demonstrating that brush invades grasslands even in the absence of livestock grazing. Once established, brush effectively monopolizes soil moisture and nutrients, and grass reestablishment is generally very limited without selective control of brush species. However, traditional brush control practices are expensive and frequently only of short-term effectiveness. New technologies are needed, but at present there are few management options for controlling continued brush encroachment.

Animals Found on the Jornada Experimental Range

Large herbivores:

Pronghorn antelope	*Antilocapra americana*
Mule deer	*Odocoileus hemionus*
Desert bighorn sheep	*Ovis canadensis mexicanus*
Gemsbok (oryx)	*Oryx gazella*

Carnivorous mammals:

Coyote	*Canis latrans*
Gray fox	*Urocyon cinereoargenteus*
Desert fox	*Vulpes macrotis*
Badger	*Taxidea taxus*
Bobcat	*Felis rufus*
Striped skunk	*Mephitis mephitis*

Small mammals:

Ord's kangaroo rat	*Dipodomys ordii*
Merriam's kangaroo rat	*Dipodomys merriami*
Banner-tailed kangaroo rat	*Dipodomys spectabilis*
White-throated wood rat	*Neotoma albigula*
Southern plains wood rat	*Neotoma micropus*
Silky pocket mouse	*Perognathus flavus*
Spotted ground squirrel	*Spermophilus spilosoma*
Deer mouse	*Peromyscus maniculatus*
Harvest mouse	*Reithrodontomys megalotis*
Desert cottontail	*Sylvilagus audubonii*
Blacktailed jackrabbit	*Lepus californicus*

Birds:

Roadrunner	*Geococcyx californianus*
Redtailed hawk	*Buteo jamaicensis*
Swainson's hawk	*Buteo swainsoni*
Golden eagle	*Aquila chrysaetos*
Burrowing owl	*Speotyto cunicularia*
Mourning dove	*Zenaida macroura*
Gambel quail	*Lophortyx gambelii*
Scaled quail	*Callipepla squamata*
Black-throated sparrow	*Amphispiza bilineata*
Western kingbird	*Tyrannus verticalis*
Scott's oriole	*Icterus parisorum*
Curve-billed thrasher	*Toxostoma curvirostre*
Lesser nighthawk	*Chordeiles acutipennis*
Chihuahuan raven	*Corvus cryptoleucus*
Cactus wren	*Campylorhynchus brunneicapillus*
Turkey vulture	*Cathartes aura*
White-crowned sparrow	*Zonatrichia leucophrys*
Lark Bunting	*Calamospiza melanocorys*

Animals Found on the Jornada Experimental Range (continued)

Reptiles and amphibians:

Prairie rattlesnake	*Crotalus viridis*
Diamondback rattlesnake	*Crotalus atrox*
Texas horned lizard	*Phrynosoma cornutum*
Side-blotched lizard	*Uta stansburiana*
Western whiptail lizard	*Cnemidophorus tigris*
Little striped whiptail	*Cnemidophorus inornatus*
Gopher snake	*Pituophis melanoleucus*
Western spadefoot toad	*Spea multiplicata*
Couch's spadefoot toad	*Scaphiopus couchi*

Insects:

Lesser migratory locust	*Melanoplus sanguinipes*
Snakeweed grasshopper	*Hesperotettix viridis*
Painted lady butterfly	*Vanessa cardui*
Harvester ant	*Pogonomyrmex rugosus*
Darkling beetle	*Eleodes hispilabris*
Subterranean termite	*Gnathamitermes tubiformans*

Wildlife

The Jornada Experimental Range lies within the Chihuahuan biotic province. The fauna is representative of that found in the upper Sonoran and Transition Life Zones throughout the Southwest.

A small band of antelope (< 100 individuals) inhabit the Jornada Plain, and mule deer inhabit the foothills and mountains. A number of gemsbok, introduced from Africa, have taken up residence throughout the range. The ubiquitous coyote is the most abundant of the carnivorous animals. Recent studies have estimated coyote population densities at 3-4 animals/mi^2.

Rabbit and rodent populations are cyclic. Cottontails and jackrabbits combined have been censused at densities up to 1,700 animals per section (656/km^2). Several rodent species are abundant in grama grasslands and shrub dominated areas. Rodents are least abundant in the tobosa and burrograss areas. Both rodents and rabbits can consume large quantities of forage when they are abundant.

The Experimental Range, like areas throughout the northern Chihauhuan Desert, is an important wintering ground for grassland birds. Seed eaters and raptors are common during winter months.

Insect populations are seasonal and reach peak abundance during late summer. Foliage feeding insects, such as grasshoppers, can periodically reach high densities and can compete with larger herbivores for available forage. Ants, termites, and dung beetles are important scavengers. Termite biomass has been estimated at 27 lbs/acre (30 kg/ha), and termites influence important processes such as nutrient cycling, organic matter decomposition, and soil-water status.

Desert Ecology

Although extremely complex, deserts and desert grasslands are among the simplest natural landscapes found on Earth. Furthermore, these systems are extraordinarily sensitive to both human and non-human influences. Because of these two attributes, scientists have been especially reliant on desert ecosystems to develop general understandings of ecosystem processes. Scientists working in desert and grassland environments have contributed greatly to the development of ideas relating to landscape continuity, disturbance, plant-animal interactions, stability and change. These ideas futher contribute to the management of human interactions with forest, farmland and ocean ecosystems.

Earlier models of desert ecosystems suggested these system were predictable with predictions being based chiefly upon soil and climatic constraints. Ecologists have since learned that the chaotic nature of disturbance and adaptation make predictions of these ecosystem responses difficult, at best. Current paradigms are built on early ecosystem concepts, but with modifications that integrate new theories involving thermodynamics, quantum mechanics, chaos, complexity and adaptive systems.

By increasing our understanding of changes in ecosystem patterns and processes, we can learn to predict future trends with some degree of certainty. This will require integrating information from research examining ecosystems from organismal to global perspectives. This trend toward highly interactive science is occurring on the Jornada Experimental Range as scientists examining the chemistry of a single leaf closely interact with scientists modeling global chemical budgets.

Because of the Jornada Experimental Range's long history of desert research, we can examine these changes across a large landscape over a relatively long period of time. The resulting knowledge will be critical if we are going to manage human interactions with desert ecosystems in a manner to ensure these ecosystems remain vigorous while meeting societal needs.

Livestock Management

Grazing management follows a "Best Pasture System", which, as the name implies, means that if animals are moved they go to the pasture with the best forage at that time. Under this system, cattle normally use tobosa and burrograss areas during the growing season; black grama range in winter; and mesquite sand dunes in late winter and spring. Flexibility in both time of grazing, and number and kind of animals is essential if arid ranges are to be properly managed.

Cattle management is fairly typical of range livestock operations in the Southwest. The cattle herd is a commercial crossbred type (primarily Angus x Hereford) of mature females, 2-year-old heifers and yearling replacement heifers. Our calving season is February-April, with weaning of calves in October. Cattle are marketed either through public auction or contract, and all livestock receipts return to our operation to fund our research and management programs.

Domestic sheep were introduced on the Jornada Experimental Range in 1983. Between February 1983 and February 1984 coyotes killed 44% of the original 144 head flock. Therefore, in order to conduct studies on mixed-species stocking, protecting sheep from coyote predation became of paramount importance, and required multifaceted and innovative strategies. Guarding dogs, specifically the Turkish Akbash breed, form the backbone of our current predation management program. In addition, another strategy has been to bond sheep to cattle. Since cattle in a herd and sheep in a flock do not consistently associate as a group under free-ranging conditions, it is necessary to modify sheep behavior. To do this the two species are brought together in close association when lambs are between 45 and 90 days-of age. The resulting cohesive group we have termed a flerd. Bonded sheep consistently stay close to cattle, and when threatened by coyotes move in close proximity to cattle. Apparently this close association with cattle serves to intimidate marauding canines. Predation losses under multifaceted management of the flerd are almost non existent.

In 1994, Pastures 1A and 1B (19,833 acres) were set aside for holistic management in a cooperative agreement with the Beck Land and Cattle Company, Nutt, NM. This collaboration, labeled the Ecosystem Stewardship Project, is intent on sustaining a functional rangeland ecosystem while managing for livestock production.

Past Research (1915-1992)

Rainfall, stocking, and vegetation have been continuously recorded since 1915. Many significant contributions have been made to our understanding of the ecology and biology of native plants and animals. Much past research has been directed at problems associated with the rangeland livestock industry. Some of the contributions toward better management of arid rangelands are as follows:

1. Development of proper timing and grazing utilization standards for black grama and tobosa rangelands.
2. Improved livestock distribution techniques including water development and salting practices.
3. Establishment of principles of flexible herd management to cope with fluctuating forage supplies.
4. Improved brush-control methods.
5. Development of methods and equipment for revegetation of depleted rangelands.

A complete bibliography of the hundreds of scientific publications authored by research personnel at the Experimental Range is available upon request.

Data Management

A variety of regional data are maintained in a Geographic Information System, including layers of elevation, hydrology, geology, soils, vegetation, grazing history, physical structures, and digital remotely sensed images. Historical data sets are documented and entered into a hard disk database with personal computers as file servers. Data files are readily transferrable through a local network at New Mexico State University and Internet. Access requests, except for meterological data which are unrestricted, are treated on a case-by-case basis. Access is through data management personnel with the LTER program and protocol follows LTER network standards.

Selected Publications

Jardine, J.T. and C.L. Forsling. 1922. Range and cattle management during drought. U.S. Dept. Agric. Bull. 1031. 84 pp.

Nelson, E.W. 1934. The influence of precipitation and grazing on black grama range. U.S. Dept. Agric. Tech. Bull. 409. 32 pp.

Canfield, R.H. 1939. The effect of intensity of clipping on density and yield of black grama and tobosa grass. U.S. Dept. Agric. Tech. Bull. 681. 32 pp.

Paulsen, H.A. and F.N. Ares. 1962. Grazing values and management of black grama and tobosa grasslands and associated shrub ranges of the Southwest. U.S. Dept. Agric. Tech. Bull. 1270. 56 pp.

Buffington, L.C. and C.H. Herbel. 1965. Vegetation changes on a semidesert grassland range from 1858 to 1963. Ecol. Monog. 35:139-164.

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Fencing crew on the Jornada Range Reserve in October, 1912.
Mr. C. Turney seated at far right.

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