COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 00-2

NSF 00-2 02/01/00

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

Long-Term Ecological Research

FOR NSF USE ONLY

NSF PROPOSAL NUMBER

0080412

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				173851965	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYMS(S)
856000401	☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE

New Mexico State University

AWARDEE ORGANIZATION CODE (IF KNOWN)

0026575000

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE

Box 30001
Dept. 3699
Las Cruces, NM. 880038001

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE

PERFORMING ORGANIZATION CODE (IF KNOWN)

ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE

IS AWARDEE ORGANIZATION (Check All That Apply)
(See GPG II.D.1 For Definitions) ☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT **Jornada Basin LTER IV: Linkages in Semi-arid Landscapes**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ 4,200,000	72 months	10/01/00	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☐ BEGINNING INVESTIGATOR (GPG 1.A.3)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.D.1)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG II.D.10)
- ☐ NATIONAL ENVIRONMENTAL POLICY ACT (GPG II.D.10)
- ☐ HISTORIC PLACES (GPG II.D.10)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.12)
- ☐ GROUP PROPOSAL (GPG II.D.12)
- ☐ VERTEBRATE ANIMALS (GPG II.D.12) IACUC App. Date ____
- ☐ HUMAN SUBJECTS (GPG II.D.12)
  Exemption Subsection ____ or IRB App. Date ____
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES ____
- ☐ FACILITATION FOR SCIENTISTS/ENGINEERS WITH DISABILITIES (GPG V.G.)
- ☐ RESEARCH OPPORTUNITY AWARD (GPG V.H)

PI/PD DEPARTMENT

Department of Biology

PI/PD FAX NUMBER

505-646-5665

PI/PD POSTAL ADDRESS

Box 30001, Dept. 3AF

Las Cruces, NM 88003
United States

NAMES (TYPED)	High Degree	Yr of Degree
PI/PD NAME Laura F Huenneke	Ph.D.	1983
CO-PI/PD Debra P Peters	Ph.D.	1988
CO-PI/PD Kris M Havstad	Ph.D.	1981
CO-PI/PD Hugh C Monger	Ph.D	1990
CO-PI/PD		

Project Summary

Jornada Basin LTER IV: Linkages in Semi-arid Landscapes

Chihuahuan Desert landscapes exemplify the ecological conditions, vulnerability, and management issues found in semi-arid regions around the globe. The goal of the Jornada Basin Long-Term Ecological Research program is to identify the key factors that control ecosystem dynamics in semi-arid landscapes, with the objective of understanding the causes and consequences of desertification. Previous LTER work has focused primarily at the scale of a single plant-interspace and on the redistribution of soil resources at that scale. However, the intrinsic nature of semi-arid regions, including the prevalence of high winds and short intense precipitation events in landscapes with substantial topographic variability, promotes the redistribution of materials at larger scales. Our central hypothesis for LTER IV is that landscape position and linkages among landscape units exert important influences on ecosystem dynamics and biotic patterns within sites. We propose to build on our understanding of resource redistribution at the plant-interspace scale in several ways. We will synthesize existing long-term data with new studies on linkages among landscape units, and we will conduct simulation modeling efforts to test the relative importance of within- versus between-unit processes. We will initiate or expand studies of landscape fluxes of water, nutrients, and organisms in order to evaluate key processes affecting ecosystem dynamics at this scale. We will also employ remote sensing to assess fluxes and processes at larger spatial scales. Cross-site studies will be used to test the generality of our hypotheses for application to management and remediation of semi-arid ecosystems and desertified landscapes.

JORNADA BASIN LTER IV:

LINKAGES IN SEMI-ARID LANDSCAPES

SUBMITTED BY THE JORNADA LTER IV CONSORTIUM

Laura Foster Huenneke
New Mexico State University
Project Coordinator

Principal Investigators:

Athol D. Abrahams (Geography), State University of New York, Buffalo
Dale Gillette, NOAA, Research Triangle Park, NC
Vincent P. Gutschick (Biology), New Mexico State University
Kris M. Havstad, USDA-ARS Jornada Experimental Range
Jeffrey E. Herrick, USDA-ARS Jornada Experimental Range
Laura F. Huenneke (Biology), New Mexico State University
David C. Lightfoot (Biology), University of New Mexico
H. Curtis Monger (Agronomy), New Mexico State University
Anthony J. Parsons (Geography), University of Leicester, UK
Debra P. Coffin Peters, USDA-ARS Jornada Experimental Range
Al Rango, USDA-ARS, Beltsville, MD
William H. Schlesinger (Botany, Geology), Duke University
John Wainwright (Geography), Kings College, London, UK

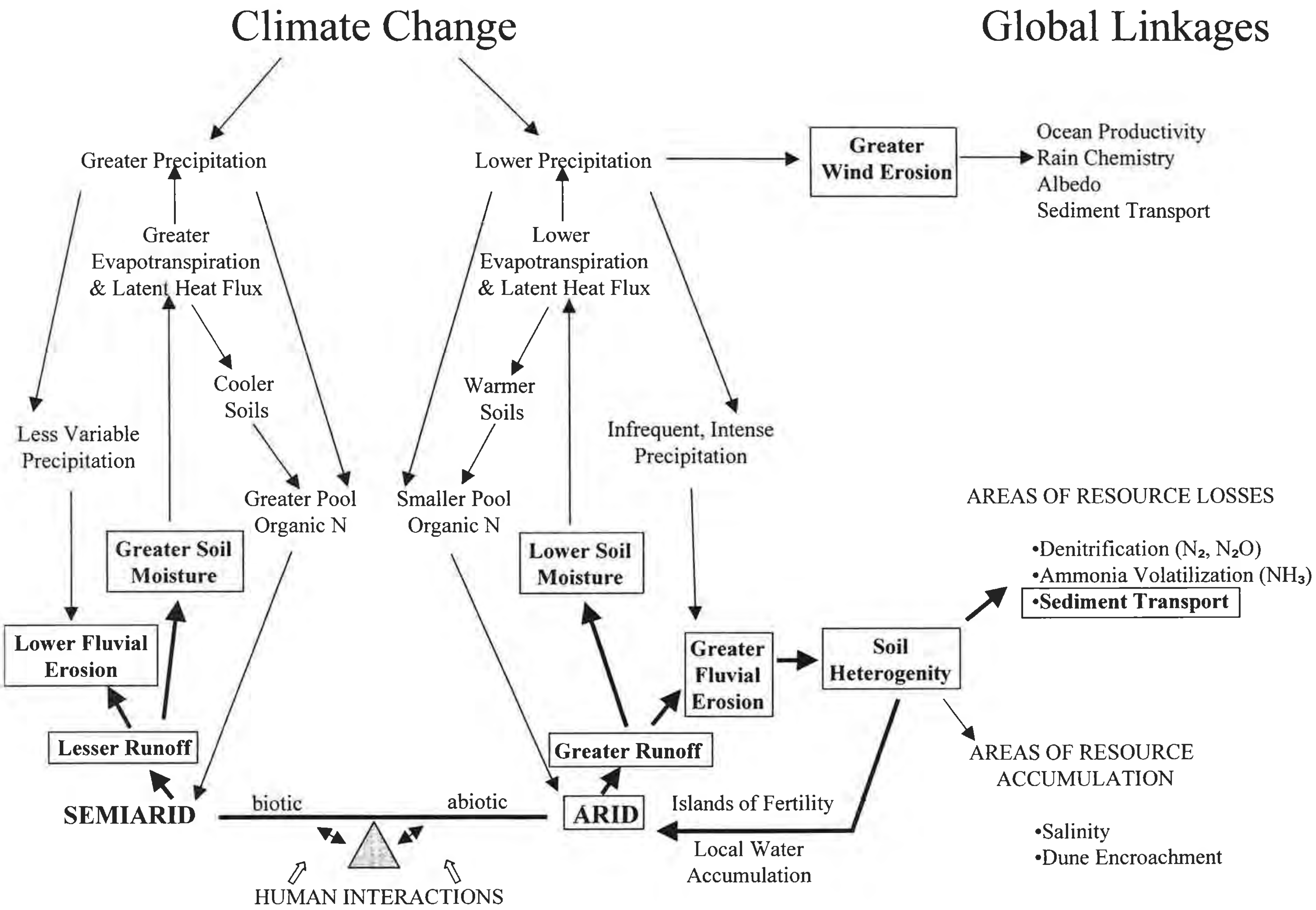


Figure 1.1 The resource-redistribution model of desertification (from Schlesinger et al. 1990) Boxes represent areas in which we made substantial progress in understanding during the Jornada LTER III funding cycle

Section 1. Results from prior support.

The Jornada Basin LTER program began in January 1982. The program has evolved substantially in conceptual approach and in participants from the original Jornada LTER I project, "Interactions in Time and Space Variability in a Chihuahuan Desert Ecosystem: Jornada LTER." The Jornada LTER I addressed the general hypothesis that spatial differences in nitrogen and water availability would impose lags in ecosystem response, and that lags (and responses) would differ between communities located in different portions of a watershed/topographic gradient. Two parallel 2.7-km transects were established, extending from the base of a desert mountain to the middle of a playa (dry lake). Aerial applications of nitrogen fertilizer were applied to one transect annually, to homogenize the patchy distribution of a limiting resource. Major results from these studies included: confirmation that nitrogen (N) availability, in interaction with water availability, can limit primary production; and indications that spatial and temporal patterns of water and N availability are related to patterns of water and organic matter transport across the landscape. We continue to derive information on water availability and plant community response from these long-term transects.

Jornada LTER II (1989 – 1993) brought a larger group of investigators together to address the hypothesis that ***desertification has altered a previous, relatively uniform distribution of water and nitrogen by increasing their spatial and temporal heterogeneity, leading to changes in community composition and biogeochemical cycling***. This model of resource redistribution as both cause and consequence of desertification was described in a 1990 paper in Science (Schlesinger et al.), and served as our general conceptual framework throughout LTER II and III.

LTER II saw us broaden our focus of attention from the original transects to an explicit consideration of all major ecosystem types of the larger Jornada basin. A network of 15 intensive study sites was established to represent the range of variation present within each of 5 ecosystem types. During the LTER II period we emphasized comparisons of the structure of the biotic communities among ecosystem types, baseline descriptions of resource availability in those ecosystem types, and tests of the major tenets of the Jornada desertification model. The permanent sites established in 1989 continue to highlight our comparative approach to understanding the dynamics within Chihuahuan desert ecosystems.

LTER III (1994 – 2000) comprised two major efforts added to the long-term studies on the 15 intensive sites: extensive work aimed at understanding the physical processes of resource redistribution by wind and water, and the establishment of two long-term experiments. These experiments were designed to test hypotheses about the role of species diversity and of interactions among multiple stressors in controlling ecosystem dynamics. We summarize below some of the major advances in our understanding during this funding period, and relate them to the tenets of the resource redistribution model (Figure 1.1).

Soil Heterogeneity and Geostatistics:

One of the central hypotheses guiding LTER II and III was that an increase in the spatial heterogeneity of soil resources leads to the progressive invasion and persistence of arid-land shrubs and to the desertification of formerly productive black grama grasslands.

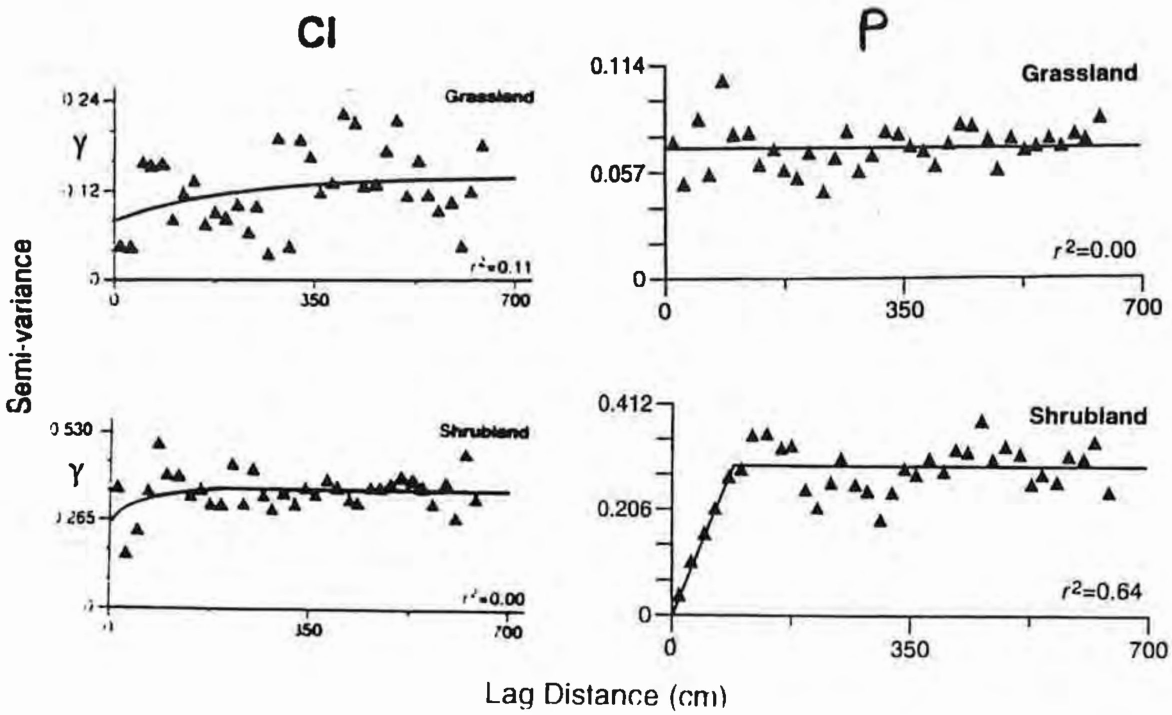


Figure 1.2. Semi-variograms for the autocorrelation of a "neutral" element, Cl, and an essential plant nutrient, P.

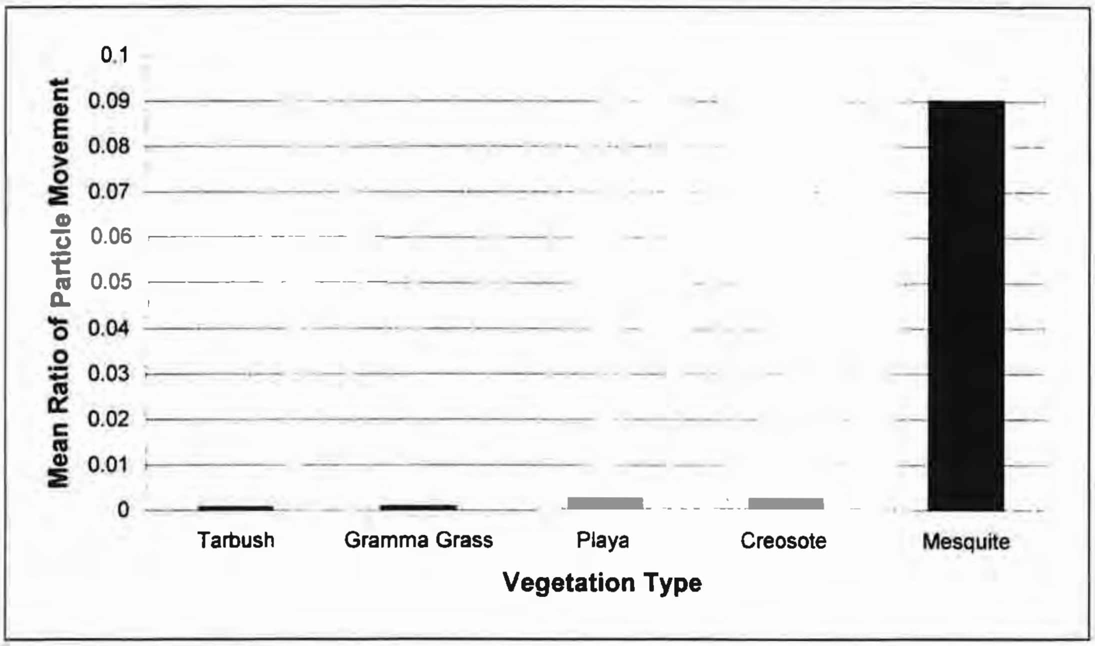


Figure 1.3. Ratios of the mean particle movements at the vegetated sites to that for the vegetation-free site for January 30 - April 30, 1998.

Such "islands of soil fertility" appear in many deserts, and we sought to test the generality of this model in the Jornada Basin and elsewhere. Using standardized methods, we collected soils in a variety of grassland/shrubland areas and in areas where creosotebush has persisted for long periods (e.g. Mojave desert). At the finest scale of our sampling (~20 cm), plant nutrients (N and P) were randomly distributed in grasslands, and more concentrated under shrubs than in the barren soils between shrubs in shrublands. Isotropic geostatistics showed that the scale of the autocorrelation in shrublands was similar to the average size of shrubs (Schlesinger et al. 1996). In contrast, non-essential nutrients (e.g., Na, Cl and Li) were randomly distributed in both grassland and shrubland habitats, suggesting that the concentration of essential plant nutrients under shrubs was due to biotic processes (Figure 1.2). Thus it appears that shrubs leave their signature on the biogeochemistry of arid-land soils (Schlesinger and Pilmanis 1998).

Radiation Balance:

Working with MEDEA -- a committee sponsored by the U.S. Defense Department -- Schlesinger and his collaborators examined the radiation balance of grassland and shrubland vegetation at the Jornada and along fenceline comparisons of the US-Mexico border. Black grama grassland has greater cover, lower albedo, and lower soil surface temperature than adjacent shrublands dominated by mesquite. Increasing desertification of semiarid grasslands by the invasion of shrubs can be expected to affect regional climate, by causing higher surface temperatures (Michalek et al. in review).

Aeolian processes:

Initial studies of wind erosion during LTER III focused on understanding dust generation at three vegetation-free (disturbed) sites on sandy soil; airborne particle fluxes at these sites are quite high. Monitoring was then expanded to measure particle fluxes at the 15 (vegetated) intensive study sites. Results document that undisturbed sandy soils in mesquite shrublands, and disturbed soils of all types, exhibit high rates of wind erosion, as expressed by calculating the ratio of the fluxes at vegetated sites to the mean flux from the disturbed or bare sites (Figure 1.3; Marticorena et al. 1997). Other soils are erodible, but only at very high winds that are experienced only rarely. The most vulnerable soils are sandy soils; these make up about half of all Jornada Basin soils. Disturbance by both cattle and humans is very important in increasing wind erosion.

The disturbed bare soil used as the comparison for dust production was studied for almost three years. Sand drift data showed the source area to be "supply limited." On the average, this source area produces dust at a rate roughly one-third that of a thick deposit of loose sandy soil. Interpretation of the data by a model of sand transport showed that the source of the material was abrasion of the surface crust. The abrasion was dominated by very high wind episodes.

Geomorphology and soils as indicators of redistribution processes:

Another example of differences in redistribution processes among ecosystem types was found by comparing carbon isotopes of modern soils with underlying paleosols along bajada transects in the northern Chihuahuan Desert (Monger et al. 1998). Upslope

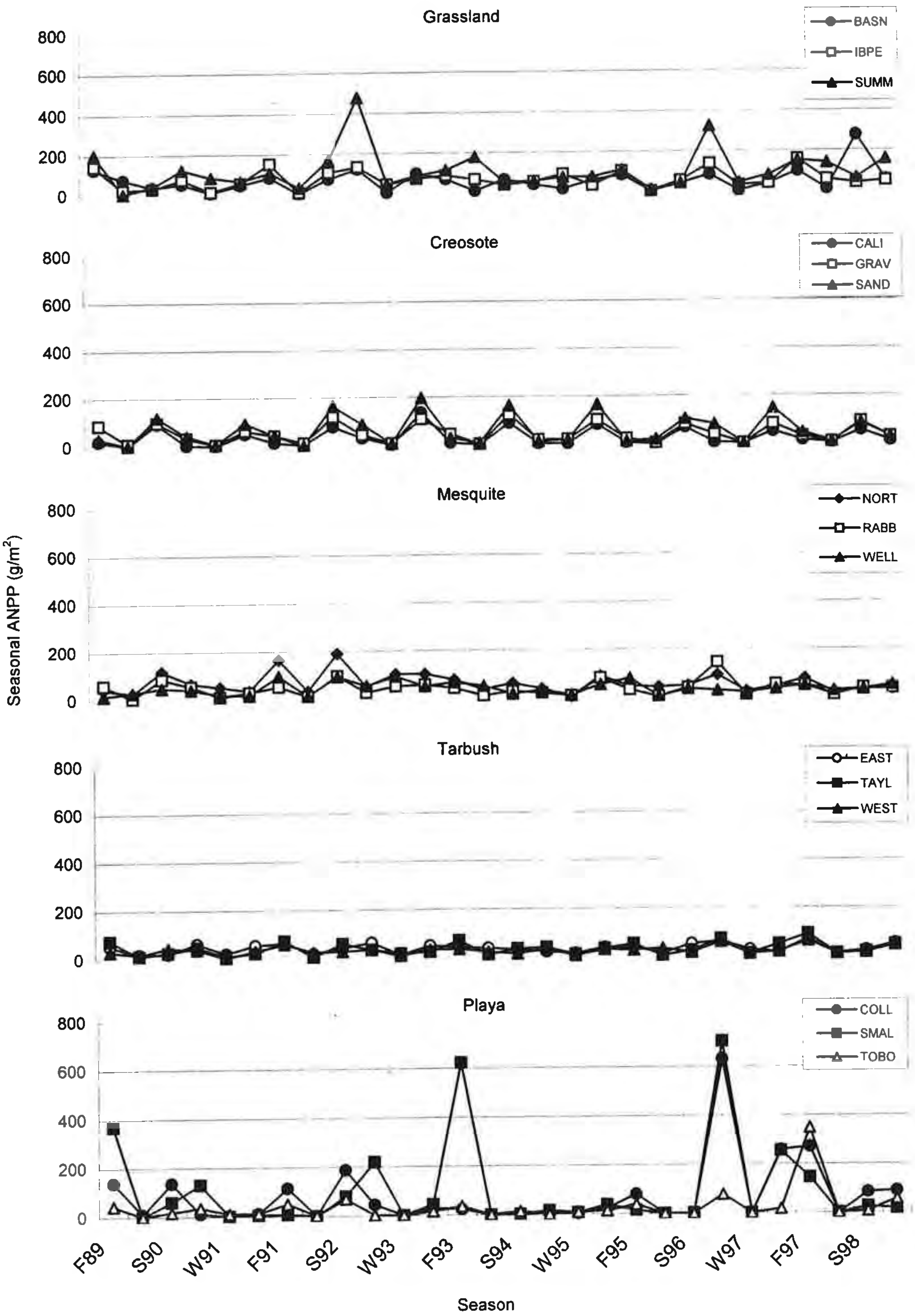


Figure 1.4. Seasonal aboveground net primary production (ANPP) for winter (W), spring (S), and fall (F) intervals, fall 1989 through winter 1999, at 15 sites in the Jornada Basin.

or higher portions of bajada slopes, where soils are rocky, have low available water holding capacities, and lose runoff water. Large shifts in carbon isotopes in these areas indicate a vegetative change from C4 to C3 plants during the middle Holocene. In contrast, only minor shifts in carbon isotopes occur across the mid-Holocene boundary in downslope areas, where soils are finer-textured, have higher available water holding capacities, and receive run-in water.

Patterns of net primary production:

Since 1989 we have been measuring aboveground plant biomass and net primary production (ANPP) by species in permanent quadrats on the 15 intensive study sites. Our non-destructive, spatially-explicit method allows us to characterize both spatial and temporal heterogeneity in biomass and production in a way that facilitates comparison among the 5 ecosystem types (Huenneke et al. in review). The long-term datasets we have accumulated (Figure 1.4) demonstrate that mean annual rates of ANPP do not differ significantly among ecosystem types. However, seasonality of ANPP does differ, with shrublands experiencing peak production in spring and the C4-dominated grasslands with highest productivity generally in the late summer-fall. Inter-annual variability is substantial for nearly all sites studied, reflecting the high variation in climatic factors (particularly precipitation) from year to year. Grass-dominated ecosystems demonstrate greater temporal variation in production than do shrub-dominated systems (Figure 1.4). On the other hand, in accord with the predictions of the resource redistribution model of desertification, aboveground biomass and productivity are distributed more patchily in shrublands than in grasslands.

Another confirmation that shrubs contribute to reduced temporal variation and enhanced spatial variation comes from an experiment excluding seasonal rainfall from shrub islands. Reynolds et al. (1999) demonstrated that even at a small size, both creosotebush and mesquite shrubs are highly effective in concentrating resources and in maintaining physiological activity in the face of severe drought.

Consumer studies:

Lizard and ground-dwelling arthropod data from our 12 intensive study sites (no playa pitfalls) demonstrate considerable annual and seasonal variation, both within and between ecosystem types (see data and summaries, http:/www.jornada.nmsu.edu/). These animal groups generally respond positively to increased precipitation and ANPP over time. However, animal responses to ecosystem productivity were not as pronounced as predicted, probably because we monitor predators and detritivores (primarily) rather than herbivores. Some species show independent, unexplained long-term trends that do not correlate with ANPP or with abundance of other species. Results from the Small Mammal Exclosure Study also demonstrate the same patterns of variability for rodents (Figure 1.5), rabbits, ants, grasshoppers, and termites. Rodents and rabbits reduced vegetation foliage cover, especially for some perennial grasses (Figure 1.6), which in turn reduced nest densities of seed-harvesting ants (Figure 1.7). These studies demonstrate that animal consumers are linked to climate, ANPP, as well as to one another. Our data provide convincing evidence that animal consumers can indeed influence the structure and function of semi-arid ecosystems.

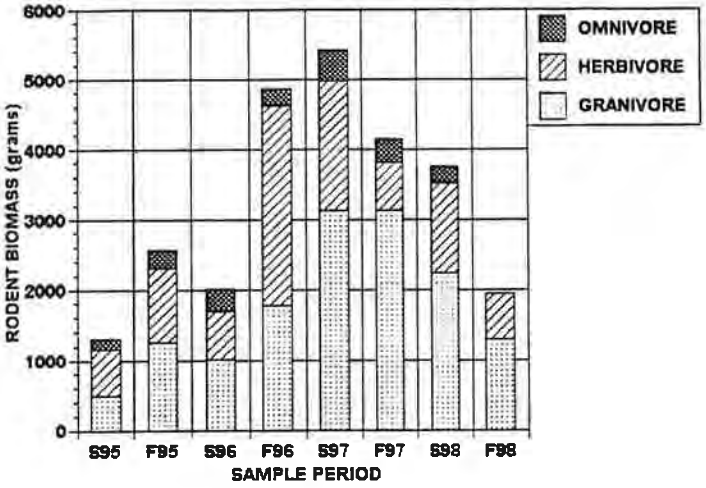


Figure 1.5. Rodent biomass by feeding habit in trapping webs at the Jornada, 1995 – 1998.

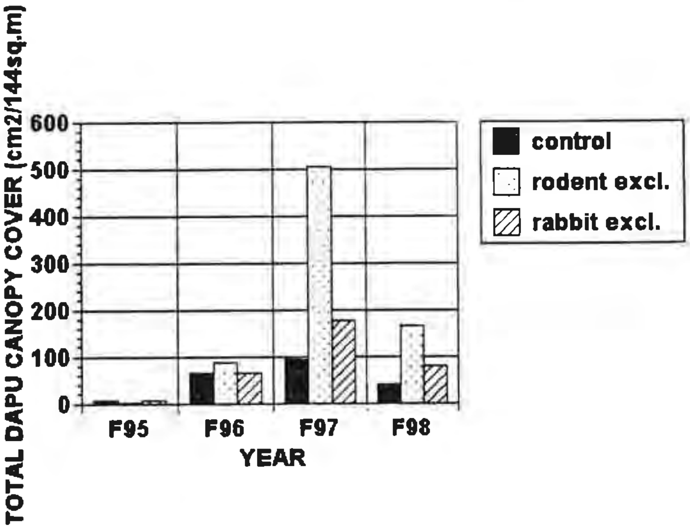


Figure 1.6. Total fluffgrass (DAPU) canopy cover summed over four replicate plots per treatment at the Jornada creosotebush site.

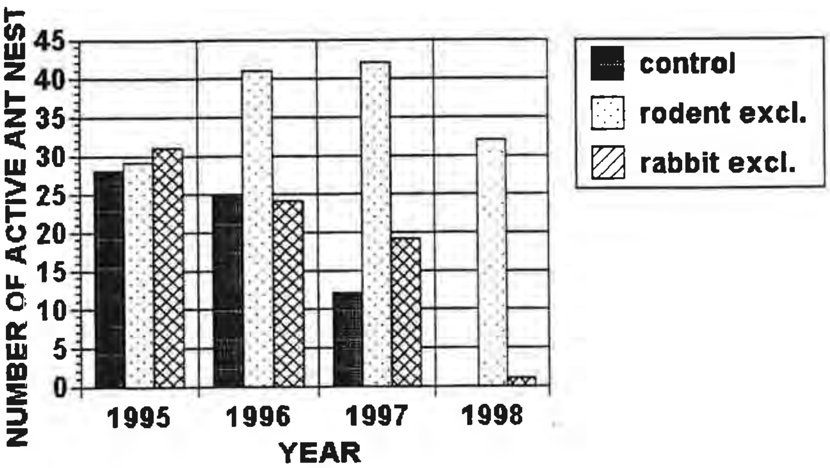


Figure 1.7. Number of active *Pogonomymex desertorum* nests counted in autumn of each year, summed over all four replicate study plots of each experimental treatment at the Jornada creosotebush site.

Hydrology and redistribution of materials by surface water flow:

During LTER III, our research has concentrated on the processes of runoff generation and sediment and nutrient transport in the creosotebush shrubland, grassland, and degraded grassland on the bajada of Mt. Summerford. Field experiments using simulated rainfall have confirmed that the form of vegetation cover (shrub vs. grass vs. open or bare) strongly influences surface hydrology. First, for creosotebush shrubs, mean stemflow rates average 35% of rainfall, regardless of rainfall rate. Sub-canopy rainfall and kinetic energy of rain are reduced beneath creosotebush canopy; these differential splash processes contribute to the formation of mounds beneath shrubs (Wainwright et al. 1999). The presence or absence of grass cover beneath a shrub is an important control on infiltration versus runoff losses; where grass is present, higher percentages of the intercepted rainfall actually infiltrate (Abrahams et al. in press). Runoff losses of nitrogen from grassland and shrub plots were similar and much less than from bare intershrub plots. Concentrations of dissolved N were greatest in grasslands and lowest in the intershrub plots. Total annual loss of N in runoff is estimated as 0.25 kg $ha^{-1}y^{-1}$ from bajada grasslands and 0.43 kg $ha^{-1}y^{-1}$ from bajada shrublands (Schlesinger et al. 1999).

Development of surface crust leads to significant differences in runoff between vegetated plots and intershrub or degraded grassland plots on the bajada. Animal digging activity has relatively little effect on runoff but is a major influence on sediment yield, because the digging disrupts the surface crust and loose sediment is scattered over the soil surface (Neave 1999).

We have also investigated flows in channels or rills. Simulated flows in sand-bed rills have shown that transmission losses over 5-m reaches are as high as 50 % of the inflow and appear to depend on the hydraulic head (Parsons et al. in press). Field monitoring of two small watersheds on the bajada has revealed that transmission losses are particularly high in areas of dispersed flow (termed "beads"). These beads are major sinks for water, sediment, and nutrients and have great potential as rangeland remediation sites (Abrahams et al. in press). An event-based two-dimensional rainfall-runoff model has been developed and applied to the two monitored watersheds to obtain a detailed understanding of the hydrology and hydraulics of overland flow on the bajada. The model shows that surface crusting is an important control on runoff response to rainfall, and suggests that runon infiltration may contribute measurably to infiltration in particular portions of each watershed (Howes 1999).

Plant diversity experiment:

During LTER III we initiated a major long-term experiment investigating the impact of altered plant species and functional group diversity. A diverse creosotebush-dominated community was manipulated by the removal of functional groups (shrubs, perennial grasses, succulents, or subshrubs), or by the removal of species within functional groups, from experimental plots. Vegetation response to treatments suggests asymmetric interactions among functional groups; for example, early trends showed shrubs responding favorably to the removal of perennial grasses, but no strong response by grasses to the removal of shrubs. Sediment movement across the surface of these plots varies seasonally (windy vs. rainy seasons) and spatially (with location on the slope), and there are significant treatment differences in at least some seasons. Animal activity in the plots has responded significantly to the manipulations. For example,

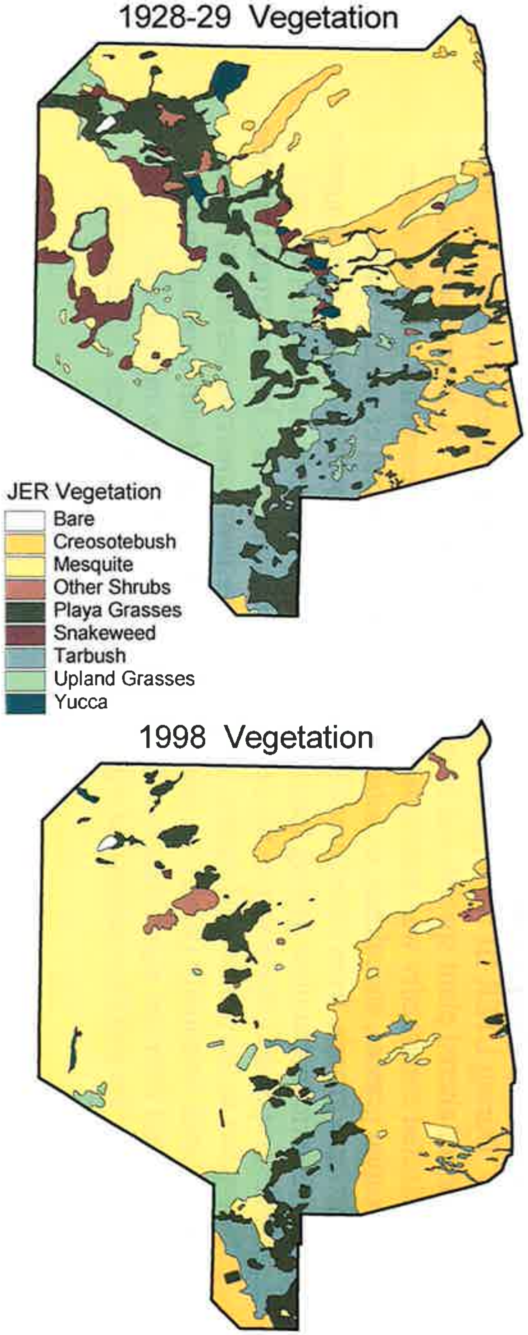


Figure 1.8. Vegetation change on the JER.

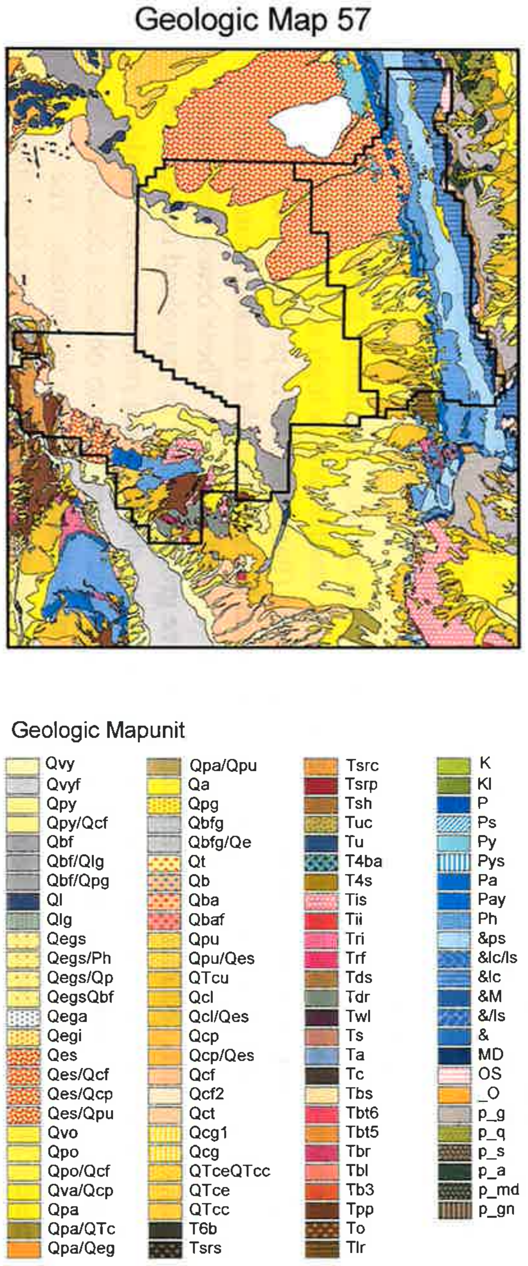


Figure 1.9. Geology of the Jornada Basin.

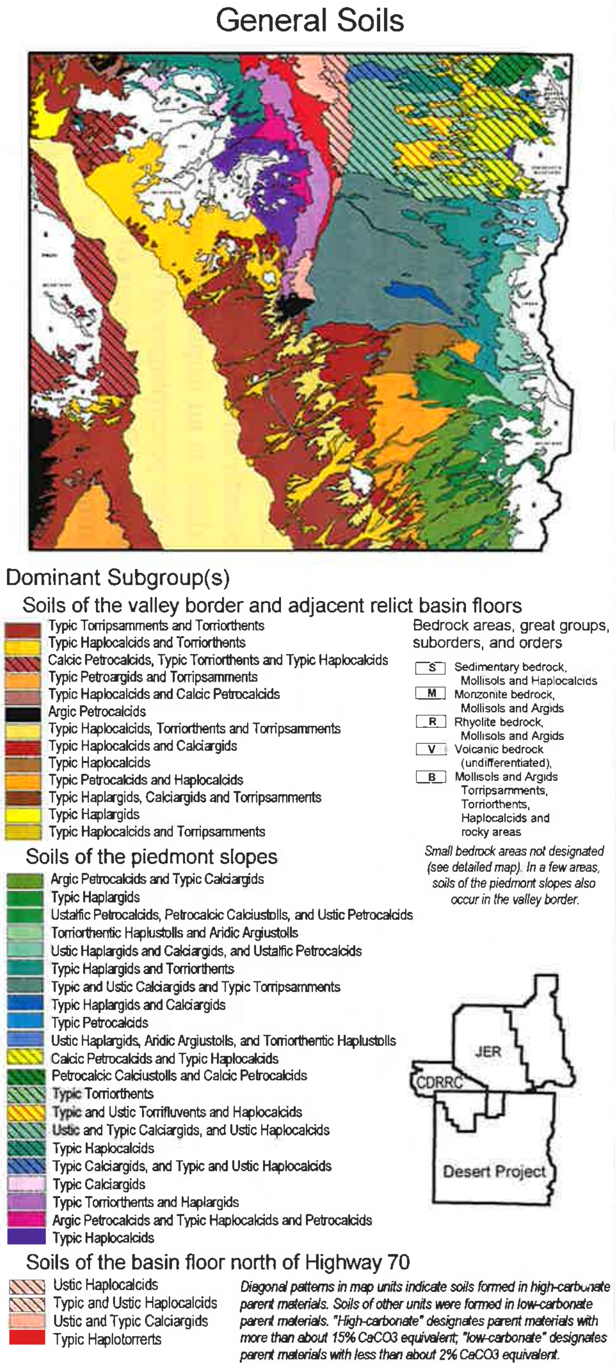


Figure 1.10. Desert Soils Project general soils map.

Zeisset (1998) found that grasshopper abundance and composition responded to altered plant functional group diversity but that ant community composition appeared to be correlated only with the volume of plant canopy present, not with plant composition.

GIS and spatial data

Recent supplements for GIS activities funded the creation of digital vegetation maps for the JER and CDRRC in cooperation with JER. These maps include the rescue of a JER vegetation map dating from 1928 - 1929, and a vegetation map of the JER and CDRRC created in a 1998 field survey using 1996 CIR photography. Figure 1.8 illustrates vegetation change on the JER by comparing these maps (1928-29 vegetation vs. 1998 vegetation). In addition, we have digitized the Buffington and Herbel (1965) historic paper maps of vegetation in 1858, 1915, and 1928.

The geologic map (Geologic Map 57: Geology of east half of Las Cruces and northeast El Paso, 1 x 2 degree sheets, New Mexico; Seager et al. 1987) was converted to digital form using a new method involving use of the original cartographic scribe sheets; this proved to be more effective and more accurate than traditional digitizing. This project was a cooperative effort between the Jornada LTER, Water Resources Research Institute, and New Mexico Bureau of Mines and Mineral Resources. A portion of the geologic map is shown in Figure 1.9. A cooperative effort of the NRCS and the Jornada LTER is producing 16 maps of soil distributions for the Jornada basin, extending mapping work done in 1957-1972 as part of the original Desert Soil-Geomorphology Project (Desert Project). Figure 1.10 illustrates the soils currently mapped within our system.

Summary:

The Jornada Basin LTER program began with a focus on the response of desert ecosystems to spatial and temporal variation in resource availability. By the start of LTER II, this focus had been formalized as the Jornada resource redistribution model of desertification (Figure 1.1; Schlesinger et al. 1990). The 15 intensive study sites established in LTER II facilitate a more comprehensive comparison of the important ecosystem types of the Chihuahuan desert region than was possible in the original LTER I transects. Our work during LTER III was primarily directed at developing a greater mechanistic understanding of the redistribution of resources by wind and water. A secondary emphasis was the establishment of long-term experiments aimed at understanding the response of Chihuahuan desert ecosystems to environmental changes and human pressures. As the close of Jornada LTER III approaches, we are prepared to take the next logical steps in the study of semiarid rangeland ecosystems. We will explore the implications of these redistribution processes at a larger, landscape scale; and we will assess the relative influence of within-site versus between-site (or landscape-level) factors in determining the unique features of Chihuahuan region ecosystems.

PUBLICATIONS LIST

The following publications appeared or were produced during the Jornada Basin LTER III cycle (1994 – 2000). They are categorized as: peer-reviewed journal articles; book chapters and conference proceedings; dissertations and theses; and other. The names of Jornada III principal investigators appear in CAPITALIZED typeface. A complete bibliography of scientific literature from the Jornada research site, including USDA-ARS, NMSU, IBP, and LTER publications, is maintained by data management personnel and is searchable by keyword or author. The complete bibliography is also available through the LTER web site, and we are moving toward making it searchable by web site visitors in the future.

PUBLICATIONS

Papers Published and In review/In press as part of the Jornada LTER-III
October 1994 -- present
(Current LTER Principal Investigators in CAPITALS)

PEER-REVIEWED JOURNAL ARTICLES

ABRAHAMS, A.D. G. Li, C. Krishnan and J.F. Atkinson. 1998. Predicting sediment transport by interrill overland flow on rough surfaces. Earth Surface Processes and Landforms 23: 481-492.

ABRAHAMS, A.D., P. Gao, and F.A. Aebly. 2000. Relation of sediment transport capacity to stone cover and size in rain-impacted interrill flow. Earth Surface Processes and Landforms, in press.

ABRAHAMS, A.D., G. Li, C. Krishnan and J.F. Atkinson. Sediment transport equations for interrill overland flow on rough surfaces. Earth Surface Processes and Landforms, submitted.

Abrams, M.M. and W.M. Jarrell. 199-. Soil spatial heterogeneity across a mesquite dune chronosequence. Oecologia, in review.

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. Ruekgauer, 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.

Anderson, D.M., E.L. Fredrickson, P. Nachman, R.E. Estell, K.M. HAVSTAD, and L.W. Murray. 1998. Laser-induced fluorescence (LIF) spectra of herbaceous and woody pre- and post-ingested plant material. Animal Feed Science and Technology 70:315-337.

Barrow, J.R., K.M. HAVSTAD, and B.D. McCaslin. 1997. Fungal root endophytes in fourwing saltbush, *Atriplex canescens*, on arid rangelands of southwestern USA. Arid Soil Research and Rehabilitation 11: 177-185.

Barrow, J.R., K.M. HAVSTAD, J. Hubstenberger, and B.D. McCaslin. 1997. Seed-borne fungal endophytes on fourwing saltbush, *Atriplex canescens*. Arid Soil Research and Rehabilitation 11: 310-314.

BassiriRad, H., D.C. Tremmel, J.F. REYNOLDS, and R.A. VIRGINIA. 199-. Short-term patterns in resource capture by two desert shrubs following a simulated summer rain. Plant and Soil, in review.

BassiriRad, H., J.F. REYNOLDS, R.A. VIRGINIA, and M.H. Brunelle. 1997. Growth and root NO_3^- and PO_4^{3-} uptake capacity of three desert species in response to atmospheric CO_2 enrichment. Australian Journal of Plant Physiology 24: 353-358.

Belnap, J. and D. GILLETTE. 199-. Disturbance of biological soil crusts: Impacts on potential wind erodibility of sandy desert soils in southeastern Utah, U.S.A. Land Degradation and Rehabilitation, in press.

Belnap, J. and D. A. GILLETTE. 1998. Vulnerability of desert soil surfaces to wind erosion: the influences of crust development, soil texture, and disturbance. J. Arid Environments 39: 133-142.

Berckman, S.K. and D.C. Lightfoot. Harvester ant (*Pogonomyrmex*) nest distribution and microhabitat characteristics across the Chihuahuan Desert. Southwestern Naturalist, in review.

Brisson, J. and J.F. REYNOLDS. 1997. Effects of compensatory growth on population processes: A simulation study. Ecology 78: 2378-2384.

Brussaard, L., V.M. Behan-Pelletier, D.E. Bignell, V.K. Brown, W.A.M. Didden, P.J. Folgarait, C. Fragoso, D.W. Freckman, V.S.R. Gupta, T. Hattori, D. Hawksworth, C. Klopatek, P. Lavelle, D. Malloch, J. Rusek, B. Soderstrom, J.M. Tiedje, and R.A. VIRGINIA. 1997. Biodiversity and ecosystem function in soil. Ambio 26: 563-570.

Buck, B.J. and H.C. MONGER. 2000. Stable isotopes and soil-geomorphology as indicators of Holocene climate change, northern Chihuahuan desert. J. Arid Environments, in press.

Chen, J.-L. and J.F. REYNOLDS. 1997. GePSI: A generic plant simulator based on object-oriented principles. Ecological Modelling 94: 53-66.

Connin, S.L., R.A. VIRGINIA, and C.P. Chamberlain. 1997. Carbon isotopes reveal soil organic matter dynamics following arid land shrub expansion. Oecologia 110: 374-386.

Connin, S.L., R.A. VIRGINIA, and C.P. Chamberlain. 1997. Isotopic study of environmental change from disseminated carbonate in polygenetic soils. Soil Science Society of America Journal 61: 1710-1722.

Connin, S. L., X. Feng, and R. A. VIRGINIA. Isotopic discrimination during long-term decomposition in an aridland ecosystem. Soil Biology and Biochemistry, in press.

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.

de Soyza, A.G., W.G. Whitford, J.E. Herrick, J.W. Van Zee and K.M. HAVSTAD. 1998. Early warning indicators of desertification: Examples of tests in the Chihuahuan desert. Journal of Arid Environments 39: 101-112.

Estell, R.E., D.M. Anderson and K.M. HAVSTAD. 1994. Effects of organic solvents on use of tarbush by sheep. Journal of Chemical Ecology 20: 1137-1142.

Estell, R.E., E.L. Fredrickson, M.R. Tellez, K.M. HAVSTAD, W.L. Shupe, D.M. Anderson, and M.D. Remmenga. 1998. Effects of volatile compounds on consumption of alfalfa pellets by sheep. Journal of Animal Science 76: 228-233.

Estell, R.E., E.L. Fredrickson, D.M. Anderson, K.M. HAVSTAD, and M.D. Remmenga. 1998. Relationship of tarbush leaf surface terpene profile with livestock herbivory. Journal of Chemical Ecology 24: 1-12.

Estell, R.E., E.L. Fredrickson and K.M. HAVSTAD. 1996. Chemical composition of *Flourensia cernua* at four growth stages. Grass Forage Science 51: 434-441.

Eve, M., W.G. Whitford, and K.M. HAVSTAD. 1999. Applying satellite imagery to triage assessment of ecosystem health. Environmental Monitoring and Assessment 54:205-207.

Fisher, F.M. and W.G. Whitford. 1995. Field simulation of wet and dry years in the Chihuahuan desert: Soil moisture, N mineralization and ion-exchange resin bags. Biology and Fertility of Soils 20: 137-146.

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

Franco, A.C., A.G. de Soyza, R.A. VIRGINIA, J.F. REYNOLDS, and W.G. Whitford. 1994. Effects of plant size and water relations on gas exchange and growth of the desert shrub, *Larrea tridentata*. Oecologia 97: 171-178.

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

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.

Fredrickson, E.L., W.L. Shupe, R.E. Estell, K.M. HAVSTAD, and L.W. Murray. Effects of feeding ewe lambs 15% tarbush pellet pre- and post-weaning on subsequent diet selection of tarbush. Journal of Arid Environments, in review.

Fredrickson, E., K.M. HAVSTAD, R. Estell and P. Hyder. 1998. Perspectives on desertification: Southwestern United States. Journal of Arid Environments 39: 191-207.

Fryrear, D.W., J.B. Ziao, and D. GILLETTE. Aerodynamic equivalent diameter of particles using VSAT. Journal of Geophysical Research, in review.

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

GILLETTE, D.A. 200x. A qualitative geophysical explanation for "hot spot" dust emitting source regions. Contributions to Atmospheric Physics, in press.

Hartley, A.E. and W.H. SCHLESINGER. Environmental controls on nitrogen fixation in northern Chihuahuan desert soils. Soil Biology and Biochemistry, in review.

Hartley, A.E. and W.H. SCHLESINGER. Environmental controls on nitric oxide emission from northern Chihuahuan desert soils. Biogeochemistry, in review.

HAVSTAD, K.M., R.P. Gibbens, C.A. Knorr and L.W. Murray. Long-term influences of shrub competition and herbivory on Chihuahuan desert shrub vegetation dynamics. Journal of Range Management, in review.

HAVSTAD, K.M., J.E. Herrick, and W.H. SCHLESINGER. 2000. Rangelands, degradation, and nutrients. PP 77 – 87 in O. Arnalds and S. Archer (editors). Rangeland Desertification. Kluwer Academic Publishers, Dordrecht.

HERMAN, R.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.

HERMAN, R.P. 1997. Shrub invasion and bacterial community pattern in Swedish pasture soil. FEMS Microbiological Ecology 24: 235-242.

Herman, R.P., A. Langley, S. Ambro, and S. Jones. 199-. The distribution of arbuscular mycorrhizal fungi in upland and playa desert grasslands. Manuscript.

HAVSTAD, K. M., J.E. Herrick, and W.H. SCHLESINGER. Desert rangelands, degradation and nutrients. In: O. Arnalds and S. Archer, editors. Rangeland Desertification. Kluwer Academic Publishers, Dordrecht.

Herrick, J.E. and W.G. Whitford. 1995. Assessing the quality of rangeland soils: Challenges and opportunities. Journal of Soil and Water Conservation 50: 237-242.

Herrick, J.E., K.M. HAVSTAD, and D.P. Coffin. 1997. Rethinking remediation technologies for desertified landscapes. Journal of Soil and Water Conservation 52: 220-225.

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

Howes, D.A. and A.D. ABRAHAMS. In review. A stochastic model of infiltration on a spatially varied hillslope. Water Resources Research.

HUENNEKE, L.F., D. Clason and E. Muldavin. Spatial heterogeneity in Chihuahuan Desert vegetation: implications for sampling in semiarid ecosystems. Journal of Arid Ecosystems, in review.

HUENNEKE, L.F., J. Anderson, and W.H. SCHLESINGER. Spatial and temporal variation in aboveground biomass and net primary production in Chihuahuan desert ecosystems. In revision.

Kay, F.R., H.M. Sobhy and W.G. Whitford. 1999. Soil microarthropods as indicators of exposure to environmental stress in Chihuahuan desert rangelands. Biology and Fertility of Soils 28: 121-128.

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

Kerley, G.I.H., W.G. Whitford, and F.R. May. 1997. Mechanisms for the keystone status of kangaroo rats: graminivory rather than granivory? Oecologia 111: 422-428.

King, D.W, R.E. Estell, E.L. Fredrickson, K.M. HAVSTAD, J.D. Wallace, 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.

Li, G. and A.D. ABRAHAMS. 1999. Controls of sediment transport capacity in laminar interrill flow on stone-covered surfaces. Water Resources Research 35: 305-310.

Li, H. and J.F. REYNOLDS. 1994. A simulation experiment to quantify spatial heterogeneity in categorical maps. Ecology 75: 2446-2455.

Li, H. and J.F. REYNOLDS. 1995. On definition and quantification of heterogeneity. Oikos 72: 280-284.

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.

Marticorena, B., G. Bergametti, D. GILLETTE, and J. Belnap. 1997. Factors controlling threshold friction velocity in semiarid and arid areas of the United States. Journal of Geophysical Research 102: 23277-23287.

Martinez-Meza, E. and W.G. Whitford. 1996. Stemflow, throughfall and channelization of stemflow by roots in three Chihuahuan desert shrubs. J. Arid Environments 32: 271-287.

Miller, R.E., and L.F. HUENNEKE. 1996. Size decline in *Larrea tridentata* (creosotebush). Southwestern Naturalist 41: 248-250.

Miller, R.E. and L.F. HUENNEKE. In press. The relationship between density and demographic variation within a population of *Larrea tridentata*. Southwestern Naturalist.

Miller, R.E. and L.F. HUENNEKE. In press. Demographic variation within a desert shrub, *Larrea tridentata*, in response to a thinning treatment. Journal of Arid Environments.

MONGER, H.C., D.R. Cole, J.W. Gish, and T.H. Giordano. 1998. Stable carbon and oxygen isotopes in Quaternary soil carbonates as indicators of ecogeomorphic changes in the northern Chihuahuan desert. Geoderma 82: 137-172.

Moorhead, D.L., R. Sinsabaugh, A.E. Linkins and J.F. REYNOLDS. 1995. Decomposition processes: Modelling approaches and applications. Science of the Total Environment 183: 137-149.

Mun, H.T. and W.G. Whitford. 1998. Change in mass and chemistry of plant roots during long-term decomposition on a Chihuahuan Desert watershed. Biology and Fertility of Soils 26: 16-22.

Murphy, K.L., I.C. Burke, M.A. Vinton, W.K. Lauenroth, M.R. Aguilar, D.A. Wedin, and R.A. VIRGINIA. In review. Regional analysis of litter quality in the central grassland region of North America. Ecology.

Musick, H.B., G.G. Schaber, and C.S. Breed. 1998. AIRSAR studies of woody shrub density in semiarid rangeland: Jornada del Muerto, New Mexico. Remote Sensing of Environment 66: 29-40.

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.

Nash, M.S., W.G. Whitford, J. Van Zee, and K.M. HAVSTAD. 1998. Monitoring changes in stressed ecosystems using spatial patterns of ant communities. Environmental Monitoring and Assessment 51: 201-210.

Nash, M.S., J.P. Anderson, and W.G. Whitford. 1999. Spatial and temporal variability in relative abundance and foraging behavior of subterranean termites in desertified and relatively intact Chihuahuan desert ecosystems. Applied Soil Ecology 359: 1-9.

PARSONS, A.J., J. WAINWRIGHT, P.M. Stone and A.D. ABRAHAMS. 199-. Transmission losses in rills in dryland habitats. Hydrological Processes, in press.

Peters, A.J., M.D. Eve, E.H. Holt, and W.G. Whitford. 1997. Analysis of desert plant community growth patterns with high temporal resolution satellite spectra. Journal of Applied Ecology 34: 418-432.

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. and J. Chen. 1996. Modelling whole-plant allocation in relation to carbon and nitrogen supply: Coordination versus optimization: Opinion. Plant and Soil 185: 65-74.

REYNOLDS, J.F. and B. Acock. 1997. Modularity and genericness in plant and ecosystem models. Ecological Modelling 94: 7-16.

REYNOLDS, J.F., R.A. VIRGINIA, P.R. Kemp, A.G. DeSoyza and D.C. Tremmel. 1999. Impact of drought on desert shrubs: Effects of seasonality and degree of resource island development. Ecological Monographs 69: 69-106.

Sala, O.E., F.S. Chapin, and 17 others, including L.F. HUENNEKE. 2000. Global biodiversity scenarios for the year 2100. Science, in press.

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.

SCHLESINGER, W.H. and A.M. Pilmanis. 1998. Plant-soil interactions in deserts. Biogeochemistry 42: 169-187.

SCHLESINGER, W.H., A.D. ABRAHAMS, A.J. Parsons, and J. Wainwright. 1999. Nutrient losses in runoff from grassland and shrubland habitats in southern New Mexico: I. Rainfall simulation experiments. Biogeochemistry 45: 21-34

Schowalter, T.D. 1996. Arthropod associates and herbivory on tarbush in southern New Mexico. Southwestern Naturalist 41: 140-144.

Schowalter, T.D., D.C. LIGHTFOOT, and W.G. Whitford. 1999. Diversity of arthropod responses to host-plant water stress in a desert ecosystem in southern New Mexico. American Midland Naturalist 142:281-290.

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

Tellez, M.R., R.E. Estell, E.L. Fredrickson, and K.M. HAVSTAD. 1998. Essential oil of

Chrysothamnus pulchellus (Gray) Greene ssp. *pulchellus*. Journal of Essential Oil Research 10: 201-204.

Tellez, M.R., R.E. Estell, E.L. Fredrickson, and K.M. HAVSTAD. 1997. Essential oil of *Flourensia cernua* DC. Journal of Essential Oil Research 9: 619-624.

Tellez, M.R., R.E. Estell, E.L. Fredrickson and K.M. HAVSTAD. 1997. Essential oil of *Dyssodia acerosa* DC. Journal of Agriculture and Food Chemistry 45: 3276-3278.

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.

VIRGINIA, R.A. and D.W. Freckman. 1997. Soil and sediments: Linkages to new research. Bulletin of the Ecological Society of America 78: 284-285.

VIRGINIA, R. A., and D. H. Wall. 1999. How soils structure communities in the Antarctic Dry Valleys. BioScience 49:973-983.

Wainwright, J., A.J. Parsons, and A.D. ABRAHAMS. 1999. Rainfall energy under creosotebush. Journal of Arid Environments 43:111-120.

Wainwright, J. 2000. Plot-scale studies of vegetation, overland flow, and erosion interactions: Case studies from Arizona and New Mexico. Hydrological Processes, in press.

Whitford, W.G. and D. Rudolfo. 1995. Variability in soils and vegetation associated with harvester ant (*Pogonomyrmex rugosus*) nests on a Chihuahuan desert watershed. Biology and Fertility of Soils 20: 169-173.

Whitford, W.G. 1996. The importance of the biodiversity of soil biota in arid ecosystems. Biodiversity and Conservation 5: 185-195.

Whitford, W.G. 1997. Desertification and animal biodiversity in the desert grasslands of North America. Journal of Arid Environments 37: 709-720.

Whitford, W.G., J. Anderson, and P.M. Rice. 1997. Stemflow contributions to the 'fertile island' effect in creosotebush, *Larrea tridentata*. Journal of Arid Environments 35: 451-457.

Whitford, W.G., A.G. de Soyza, J.W. Van Zee, J.E. Herrick and K.M. HAVSTAD. 1998. Vegetation, soil, and animal indicators of rangeland health. Environmental Monitoring and Assessment 51: 179-200.

Wondzell, S.M., G.L. Cunningham, and D. Bachelet. 1996. Relationships between landforms, geomorphic processes, and plant communities on a watershed in the northern Chihuahuan desert. Landscape Ecology 11: 351-362.

Whitford, W.G. and H.M. Sobhy. 1999. Effects of repeated drought on soil microarthropod communities in the northern Chihuahuan Desert. Biology and Fertility of Soils 28: 121-128.

Zak, D.R., D. Tilman, R.R. Parmenter, C.W. Rice, F.M. Fisher, J. Vose, D. Milchunas, and C.W. Martin. 1994. Plant production and soil microorganisms in late-successional ecosystems: A continental-scale study. Ecology 75: 2333-2347.

Zak, J.C., R. Sinsabaugh, and W.P. MacKay. 1995. Windows of opportunity in desert ecosystems: Their implications to fungal community development. Canadian Journal of Botany 73S:1407-1414.

BOOK CHAPTERS

Buck, B.J., J. Kipp, and H.C. MONGER. 1998. Soil stratigraphy of the northern Hueco Basin, New Mexico. In G.M. Mack (ed.). *Geological Guidebook of the Las Cruces Region.* New Mexico Geological Society.

Elliott, E., D. Coleman, M. Harmon, E. Kelly and H.C. MONGER. 1999. Soil structure. PP 74-88 in: P. Robertson et al. (eds.), *Standard Soil Methods for Long-Term Ecological Research.* Oxford University Press, New York.

Grigal, D., J. Bell, R. Ahrens, R. Boone, E. Kelly, H.C. MONGER, and P. Sollins. 1999. Site and landscape characterization for ecological studies. PP 29-54 in: P. Robertson et al. (eds.), *Standard Soil Methods for Long-Term Ecological Research.* Oxford University Press, New York.

HAVSTAD, K.M. 1998. An overview of arid grasslands in the northern Chihuahuan Desert. Pp. 11-20 In: B Tellman, D.M. Finch, C. Edminster, and R. Hamre (eds). The Future of Arid Grasslands: Identifying Issues and Seeking Solutions. U.S. Department of Agriculture, Forest Service, General Technical Report RMRS-P-3

HERMAN, R.P. 199-. Arbuscular mycorrhizal fungi in desert plants. In C. Bacon and J.F. White (eds.). *The Evolution of Endophytism.* Cambridge University Press, Cambridge.

Herrera, E.A. and L.F. HUENNEKE (eds.). 1996. *Biological Diversity in the Land of Enchantment: New Mexico's Natural Heritage.* New Mexico Journal of Science 36: 1-375. (Edited volume.)

Herrick, J.E., M.A. Weltz, J.D. Reeder, G.E. Schuman, and J.R. Simanton. 1999. Rangeland soil erosion and soil quality: role of soil resistance, resilience, and disturbance regime. In: "*Soil Quality and Soil Erosion,*" Soil and Water Conservation Society, Ankeny, IA.

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

HUENNEKE, L.F. 1995. Effects of biodiversity on water distribution and quality in ecosystems. pp. 412-417. In V.H. Heywood and R.T. Watson (eds.). *Global Biodiversity Assessment.* Cambridge University Press, Cambridge.

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. 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 Role of Biodiversity: A global perspective.* John Wiley and Sons, New York.

HUENNEKE, L.F. In press. Biodiversity in desert ecosystems of the future: Responses to climate change and desertification. In O.E. Sala, F.S. Chapin, and E. Huber-Sanwald (eds.). *Future Scenarios of Biodiversity: Biological Responses to Global Change*. Springer-Verlag, New York.

Jarrell, W.M., D. Armstrong, D. Grigal, E. Kelly, H.C. MONGER, and D. Wedin. 1999. Soil water and temperature status. PP 53-73 in: P. Robertson et al. (eds.), *Standard Soil Methods for Long-Term Ecological Research.* Oxford University Press, Oxford.

Kratz, T.K., J.J. Magnuson, P. Bayley, B.J. Benson, C.W. Berish, C.S. Bledsoe, E.R. Blood, C.J. Bowser, S.R. Carpenter, G.L. Cunningham, R.A. Dahlgren, T.M. Frost, J.C. Halfpenny, J.D. Hansen, D. Heisey, R.S. Inouye, D.W. Kaufman, A. McKee and J. Yarie. 1995. Temporal and spatial variability as neglected ecosystem properties: Lessons learned from 12 North American ecosystems. pp. 359-383. In D.J. Rapport, C.L. Gaudet, and P. Calow (eds.). *Evaluating and Monitoring the Health of Large-scale Ecosystems.* Springer-Verlag, N.Y.

Lauenroth, W.K., D.P. Coffin, I.C. Burke, and R.A. VIRGINIA. 1997. Interactions between demographic and ecosystem processes: A challenge for functional types. pp. 234-254 In T.M. Smith, H.H. Shugart, and F.I. Woodward (eds.). *Plant Functional Types.* Cambridge University Press, Cambridge.

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. Goodchild (eds.), *Scaling of Remote Sensing Data for Geographical Information Systems.* Lewis Publishers, Chelsea, Michigan.

Marion, G.M. and W.H. SCHLESINGER. 1994. Quantitative modeling of soil forming processes in deserts: The CALDEP and CALGYP models. pp. 129-145. In R.B. Bryant and R.W. Arnold (eds.). *Quantitative Modeling of Soil-Forming Processes.* Soil Science Society of America, Madison, Wisconsin.

MONGER, H.C. 1995. Pedology in arid lands archaeological research: An example from southern New Mexico-western Texas. pp. 35-50. In M.E. Collins (ed.). *Pedological Perspectives in Archaeological Research* Special Publication 44, Soil Science Society of America, Madison Wisconsin.

MONGER, H.C. and E.F. Kelly. 2000. Soil silica--pathways and environmental relationships. In J.B. Dixon and D.G. Schulze (eds.). *Environmental Soil Mineralogy*. Soil Science Society of America, Madison, Wisconsin.

MONGER, H.C., L.H. Gile and J.W. Hawley. 199-. The Desert Project. In C.A. Olson (ed.). *The Soil-Geomorphology Projects of R.V. Ruhe*. Special Publication of the Geological Society of America, Boulder, Colorado.

Nordt, L., M. Collins, D. Fanning, and C. MONGER. 2000. Entisols. E224-E241 in: M.E. Sumner (ed.). *Handbook of Soil Science*. CRC Press.

Peters, A.J. and M.D. Eve. 1995. Satellite monitoring of desert plant community response to moisture availability. pp. 273-287. In D.A. Mouat and C.F. Hutchinson (eds.). *Desertification in Developed Countries.* Kluwer Academic Publishers, Dortrecht, The Netherlands.

REYNOLDS, J.F., R.A. VIRGINIA, and W.H. SCHLESINGER. 1997. Defining plant functional types for models of desertification. pp. 195-216. In T.M. Smith, H.H. Shugart and F.I. Woodward. (eds.). *Plant Functional Types* Cambridge University Press, Cambridge.

REYNOLDS, J.F. and J. Wu. 1999. Do landscape structural and functional units exist? Pp. 273-296. In J.D. Tenhunen and P.Kabat (eds.). *Integrating Hydrology, Ecosystem Dynamics, and Biogeochemistry in Complex Landscapes.* John Wiley and Sons, Berlin.

REYNOLDS, J.F., R.J. Fernandez, and P.R. Kemp. 199-. Drylands and global change: Rainfall variability and sustainable rangeland production. In K.N. Watanabe and A. Komanine (eds.). *Challenge of Plant and Agricultural Sciences to the Crisis of the Biosphere on the Earth in the 21st Century.* Landes Biosciences, Austin, Texas.

Ritchie, J.C., A. Rango, W.P. Kustas, T.J. Schmugge, and K.M. HAVSTAD. 1997. JORNEX: A remote sensing campaign to quantify rangeland vegetation patterns and change. Bulletin of the Ecological Society of America 78(4):304.

SCHLESINGER, W.H. 1994. The vulnerability of biotic diversity. pp. 245-260. In R. Socolow, C. Andrews, F. Berkhout, and V. Thomas (eds.). *Industrial Ecology.* Cambridge University Press, Cambridge.

Wall, D.H. and R.A. VIRGINIA. 199-. The world beneath our feet: Soil biodiversity and ecosystem functioning. In P. Raven and T.A. Williams (eds.). *Nature and Human Society.* National Academy of Sciences Press, Washington,D.C.

Whitford, W.G. 1995. Desertification: Implications and limitations of the ecosystem health metaphor. pp. 273-293. In R.J. Rapport, C.L. Gaudet and P. Calow. (eds.). *Evaluating and Monitoring the Health of Large-Scale Ecosystems.* Springer-Verlag, New York.

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.

Whitford, W.G., G. Martinez-Turanzas, and E Martinez-Meza. 1995. Persistence of desertified ecosystems: Explanations and Implications. pp. 319-332. In D.A. Mouat and C.F. Hutchinson (eds.). *Desertification in Developed Countries.* Kluwer Academic Publishers, Dortrecht, The Netherlands.

DISSERTATIONS AND THESES

Baggs, J. 1997. Effects of black grama (*Bouteloua eriopoda*) on community and ecosystem properties in Chihuahuan desert grassland. M.S. Thesis, New Mexico State University (L.F. Huenneke, 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).

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).

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

Gallegos, R. 1999. Biogenic carbonate, desert shrubs, and stable isotopes (M.S. Thesis, New Mexico State University (H.C. Monger, advisor).

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

Herrera-Matos, J. 1998. The biodiversity of nitrogen-efficient guild bacteria in Chihuahuan Desert soils at the Jornada Basin LTER site, New Mexico. M.S. Thesis, New Mexico State University (R.P. Herman, 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).

Howes, D.A. 1999. Modeling runoff in a desert shrubland ecosystem, Jornada Basin, New Mexico. Ph.D. Dissertation, State University of New York at Buffalo (A.D. Abrahams, advisor).

Kipp, J.M. 1998. Quaternary pedogeomorphology, paleoclimate, and geoarchaeology along the Pyramid Mountains Piedmont, southwestern New Mexico. (Ph.D. Dissertation, New Mexico State University (H.C. Monger, 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).

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

Martinez-Rios, J. 1999 The use of LANDSAT in making soil maps of the Mapimi Biosphere Reserve, Mexico. Ph.D. Dissertation, New Mexico State University (H.C. Monger, advisor).

Montes-Helu, M.C. 1997. Track-vehicle disturbance on rangeland and design of sapflow gage for desert shrubs. Ph.D. Dissertation, New Mexico State University (Tim Jones, advisor).

Neave, M. 1999. Impact of small mammal disturbances on water and sediment yields in the Jornada Basin, southern New Mexico. Ph.D. Dissertation, State University of New York at Buffalo (A.D. Abrahams, 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).

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).

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).

Zeisset, M. 1998. Effect of plant community structure on insect community structure in the Chihuahuan Desert. M.S. Thesis, New Mexico State University (L.F. Huenneke, advisor).

OTHER PUBLICATIONS, INCLUDING CONFERENCE PROCEEDINGS

Barrow, J.R. and K.M. HAVSTAD. 1996. Natural methods of establishing native plants on arid rangelands. In B.A. Roundy, E.D. McArthur, J.S. Haley and D.K. Mann (eds.). Proceedings of the Wildland Shrub and Arid Land Restoration Symposium. U.S. Forest Service, Ogden, Utah.

de Soyza, A.G., W.G. Whitford, R.A. VIRGINIA and J.F. REYNOLDS. 1996. Effects of summer drought on the water relations, physiology, and growth of large and small plants of *Prosopis glandulosa* and *Larrea tridentata*. pp. 220-223. In J.R. Barrow, E.D. McArthur, R.E. Sosebee, and R.J. Tausch (eds.). Proceedings: Shrubland Ecosystem Dynamics in a Changing Environment. U.S. Forest Service, Ogden, Utah.

Estell, R.E., E.L. Fredrickson, D.M. Anderson, K.M. HAVSTAD, and M.D. Remmenga. 1996. Tarbush leaf surface terpene profile in relation to mammalian herbivory. In J.R. Barrow, E.D. McArthur, R.E. Sosebee and R.J. Tausch. (eds.). pp. 237-241. Proceedings of the Symposium on Shrubland Ecosystem Dynamics in a Changing Climate. U.S. Forest Service, Ogden, Utah.

Everitt, J.H., M.A. Alaniz, M.R. Davis, D.E. Escobar, K.M. HAVSTAD, and J.C. Ritchie. 1997. Light reflectance characteristics and video remote sensing of two range sites on the Jornada Experimental Range. pp. 485-495. In Proceedings of the l6th Biennial Workshop on Videography and Color Photography in Resource Assessment, Weslaco, Texas.

Gile, L.H., J.W. Hawley, R.B. Grossman, H.C. MONGER, C.E. Montoya and G.H. Mack. 1995. Supplement to the Desert Project Guidebook, with emphasis on soil micromorphology. Bulletin 142, New Mexico Bureau of Mines and Mineral Resources. Socorro, N.M.

Gile, L.H., R.B. Grossman, J.W. Hawley, and H.C. MONGER. 1996. Ancient soils of the Rincon surface, northern Dona Ana County. pp. l-110. In L.H. Gile and R.J. Ahrens (eds.). *Studies of soil and landscape evolution in southern New Mexico. Supplement to the Desert Project Soil Monograph. Vol. II.* Soil Survey Investigations Report #44, Lincoln, Nebraska.

GUTSCHICK, V.P. 1996. Physiological control of evapotranspiration by shrubs: Scaling measurements from leaf to stand with the aid of comprehensive models. pp. 214-219. In J.R. Barrow, E.D. McArthur, R.E. Sosebee, and R.J. Tausch. (eds). Proceedings: Shrubland Ecosystem Dynamics in a Changing Environment. U.S. Forest Service, Ogden, Utah.

HAVSTAD, K.M. and R. Beck. 1996. Research in the Jornada basin of southern New Mexico: A field tour. pp. 269-272. In J.R. Barrow, E.D. McArthur, R.E. Sosebee and R.J. Tausch. (eds.). Proceedings of the Symposium on Shrubland Ecosystem Dynamics in a Changing Environment. U.S. Forest Service, Ogden, Utah.

HAVSTAD, K.M. and W.H. SCHLESINGER. 1996. Reflections on a century of rangeland research in the Jornada Basin of New Mexico. pp. 10-15. In J.R. Barrow, E.D. McArthur, R.E. Sosebee and R.J. Tausch (eds.). Proceedings of the Symposium on Shrubland Ecosystem Dynamics in a Changing Environment. U.S. Forest Service, Ogden, Utah.

HAVSTAD, K.M. 1996. Legacy of Charles Travis Turney: The Jornada Experimental Range. Archaeological Society of New Mexico Annual Volume 22: 77-92.

HAVSTAD, K.M. 199-. Animal Husbandry. In A.S. Goudie and D.J. Cuff (eds.). *Encyclopedia of Global Change.* Oxford University Press.

HUENNEKE, L.F. 1999. A helping hand: facilitation of plant invasions by human activities. PP 562-566 in: D. Eldridge and D. Freudenberger, eds. People and Rangelands: Building the Future. Proceedings of the VI International Rangeland Congress, Townsville, Australia, July 1999. International Rangeland Congress Inc., Aitkenvale, Queensland, Australia.

HUENNEKE, L.F. 1996. Shrublands and grasslands of the Jornada Long-Term Ecological Research Site: Desertification and plant community structure in the northern Chihuahuan desert. pp. 48-50. In J.R. Barrow, E.D. McArthur, R.E. Sosebee and R.J. Tausch. Proceedings: Shrubland Ecosystem Dynamics in a Changing Environment. U.S. Forest Service, Ogden, Utah.

MONGER, H.C. 1999. Natural cycles of desertification in the Chihuahuan Desert, North America. PP 209-223 in: Proceedings of the Fifth International Conference on Desert Development. Texas Technological University Press, Lubbock.

MONGER, H.C. and W.C. Lynn. 1996. Clay mineralogy of the Desert Project and Rincon soils. pp. 111-155. In L.H. Gile and R.J. Ahrens (eds.). *Studies of soil and landscape evolution in southern New Mexico. Supplement to the Desert Project Soil Monograph, Vol. II.* Soil Survey Investigations Report, Lincoln, Nebraska.

Pilmanis, A.M. and W.H. SCHLESINGER. 199-. Spatial assessment of desertification in terms of vegetation pattern and available soil nitrogen. In Proceedings of the 5th International Conference on Desert Development, Texas Tech University, Lubbock.

Rango, A., J.C. Ritchie, W.P. Kustas, T.J. Schmugge, K.S. Humes, L.E. Hipps, J.H. Prueger, and K.M. HAVSTAD. 199-. JORNEX: A multidisciplinary remote sensing campaign to quantify plant community/atmospheric interactions in the northern Chihuahuan desert of New Mexico. Proceedings of the Annual Meeting of the American Meteorological

Society, Phoenix, Arizona.

Ritchie, 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.

SCHLESINGER, W.H. 199-. Desertification. In A.S. Goudie and D.J. Cuff (eds.). *Encyclopedia of Global Change.* Oxford University Press.

Thompson, J. and L.F. HUENNEKE. 1996. Nurse plant associations in the Chihuahuan desert shrublands. pp. 158-164. In J.R. Barrow, E.D. McArthur, R.E. Sosebee and R.J. Tausch (eds.). Proceedings: Shrubland Ecosystem Dynamics in a Changing Environment. U.S. Forest Service, Ogden, Utah.

JORNADA DATASETS

The following datasets are maintained in electronic form by the Jornada LTER information management system. Older datasets, particularly from IBP and USDA-ARS projects predating LTER I, are being added to this list as time and resources allow their recovery, documentation, and quality assurance. This list represents the current contents of the Jornada LTER Data Catalog. We note in the table below whether datasets and associated meta-data are displayed on the Jornada web site, and whether datasets are listed as open-access (accessible without approval of responsible investigator) or restricted (available after approval from the responsible investigator). Those open-access datasets not provided on the web are maintained in electronic form in the system, but are available only upon request from the data manager because of data quality assurance and control issues (proofing and QA/QC not yet completed; methods used in data collection not yet validated; legacy/historical datasets where complete documentation has not yet been recovered). Those datasets listed as restricted are also maintained in electronic form and require release authorization from the responsible investigator because one of the following conditions applies, in accord with LTER Network standards:

- legal issues (e.g., location of vulnerable resources, copyrighted imagery);
- publication issues (student or post-doc datasets where results have not yet been published; active long-term study planned to detect trends longer than one funding cycle; active short-term cycle not yet completed).

Restricted access is not a permanent condition and we review the status of restricted datasets frequently. Functionally, most ‘restricted’ datasets are in fact available to collaborators. We append a list of requests that includes restricted datasets and the response provided (in most cases, very rapid provision of the data in electronic form). Notification of the data manager is requested prior to download of web data. However, as is the case for most LTER sites, we have no absolute means of determining use of unrestricted datasets from the web site. We have counts on the number of visits to particular pages or datasets via the Internet for certain time periods, but cannot determine from these whether data are downloaded and used.

Jornada LTER Data Catalog (sorted by Status, Access, Organization, then Study)

S	Status (A=active, C=completed)
A	Access (O=open-unrestricted, R=restricted-requires release authorization of P.I.)
P.I.	Principal Investigator
DD	Documentation on web
DS	Data on web
O	Organization (1,2,3=LTER-I,-II,-III I=IBP R=LTER-related U=USDA)

STUDY	**S**	**A**	**P.I.**	**DD**	**DS**	**O**
dryfall deposition chemistry data	A	O	schlesinger	Y	Y	1
evaporation pan data - jornada lter	A	O	whitford/anderson	Y	Y	1
lter weather station climatological data	A	O	anderson			1
transect soil water content	A	O	virginia	Y	Y	1
transect soil water content - raw data	A	O	virginia	Y	Y	1
upper trailer precipitation	A	O	whitford/anderson			1
upper trailer summary precipitation data	A	O	whitford/anderson			1
wetfall deposition chemistry data	A	O	schlesinger	Y	Y	1
annual aboveground npp - summary	A	O	huenneke	Y	Y	2
lidet	A	O	harmon	Y	Y	2
npp harvest data	A	O	huenneke	Y	Y	2
seasonal aboveground npp - summary	A	O	huenneke	Y	Y	2
seasonal mean aboveground biomass - summary	A	O	huenneke	Y	Y	2
biodiversity tbrg - daily summary	A	O	huenneke	Y	Y	3
biodiversity tbrg - by event	A	O	huenneke	Y	Y	3
biodiversity tbrg - monthly summary	A	O	huenneke	Y	Y	3
dipstick rain gauge data	A	O	anderson	Y	Y	3
summary: daily totals, TBRG precip - NPP site	A	O	anderson	Y	Y	3
summary: hourly totals, TBRG precip - NPP	A	O	anderson	Y	Y	3
summary: minute totals, TBRG precip - NPP	A	O	anderson	Y	Y	3
summary: monthly totals, TBRG precip - NPP	A	O	anderson	Y	Y	3
tipping bucket rain gauge precip - NPP sites	A	O	anderson	Y	Y	3
usda standard can rain gauge	A	O	havstad			U
boundary fenceline vegetation	A	R	huenneke	Y		1
boundry fenceline vegetation	A	R	huenneke/anderson			1
transect plantline intercepts	A	R	huenneke	Y		1
lizard pitfall traps	A	R	whitford/lightfoot	Y		2
npp grg precipitation	A	R	anderson	Y	Y	2
npp perennial plant phenology transects	A	R	huenneke	Y		2
npp plant tissue chemistry	A	R	virginia/jarrell			2
npp quadrat biomass by species and season	A	R	huenneke	Y		2

STUDY	S	A	P.I.	DD	DS	O
npp quadrat data	A	R	huenneke	Y		2
npp soil water content	A	R	virginia	Y		2
seasonal aboveground npp by species per plot	A	R	huenneke	Y		2
termite bait data	A	R	whitford	Y		2
abrasion of crust	A	R	gillette	Y		3
arthropod pitfall trap-III	A	R	lightfoot	Y		3
biodiversity npp quadrat	A	R	huenneke			3
sand mass flux	A	R	gillette	Y		3
smes rodent trapping data	A	R	lightfoot	Y		3
smes vegetation line intercept data	A	R	lightfoot	Y		3
smes vegetation quadrat data	A	R	lightfoot	Y		3
soil erosion pan	A	R	huenneke	Y		3
threshold friction velocity	A	R	gillette	Y		3
vegetation transects	A	R	huenneke	Y		3
wind and sand motion	A	R	gillette	Y		3
% disturbance on lter control transect	C	O	whitford			1
% disturbance on lter treatment transect	C	O	whitford			1
1986 transect termite data	C	O	whitford			1
caliche study soil water potential	C	O	schlesinger/fonteyn			1
deep soil microarthropods	C	O	virginia			1
hydrology runoff creosotebush plots	C	O	ward/bolton/schlesinger			1
hydrology site precipitation	C	O	whitford/anderson			1
ion analysis of pond water	C	O	whitford			1
kangaroo rat mound disturbance	C	O	whitford/mun			1
larrea leaf area	C	O	whitford			1
leaching mineralization potential survey	C	O	fisher			1
litterbag data	C	O	whitford			1
litterbag organic mass loss - summary	C	O	whitford			1
litterbag root biomass loss	C	O	whitford/mun			1
litterbag root chemistry	C	O	whitford/mun			1
lysimeter - jornada soil physics	C	O	wierenga			1
mesquite foliage insects	C	O	whitford			1
mesquite phenology	C	O	virginia			1
mesquite tissue tkn and tp concentrations	C	O	virginia			1
mites from root tube extractions	C	O	virginia			1
nitrogen mineralization in mesquite cores	C	O	virginia			1
plant nutrients beneath mesquite	C	O	virginia			1
poppy mound mineralization data	C	O	fisher			1
rhizobium beneath mesquite	C	O	virginia			1
root tube mites	C	O	virginia			1
root tube soil nutrients	C	O	virginia			1
saturation extracts of mesquite soil cores	C	O	virginia			1

STUDY	S	A	P.I.	DD	DS	O
soil micronutrients for mesquite soil core	C	O	virginia			1
soil nutrients beneath mesquite	C	O	virginia			1
soil nutrients in deep cores	C	O	virginia			1
surface mites beneath mesquite	C	O	virginia			1
surface nematodes beneath mesquite	C	O	virginia			1
surface soil microarthropods beneath mesquite	C	O	virginia			1
surface soil nematodes beneath mesquite	C	O	virginia			1
surface soil nitrogen in different canopy positions ...	C	O	virginia			1
surface soil nutrients beneath mesquite	C	O	virginia			1
termite +/- litterfall traps	C	O	whitford			1
transect air temperatures	C	O	ludwig/cunningham			1
transect ants data	C	O	conley, m.			1
transect creosote litterfall	C	O	whitford			1
transect mesquite litterfall	C	O	whitford			1
transect n03 + n02-n and nh4-n levels in soil	C	O	whitford/fisher			1
transect photo quad slides	C	O	ludwig/huenneke			1
transect precipitation every 5th station	C	O	whitford			1
transect precipitation every station	C	O	cunningham			1
transect rabbit litter	C	O	whitford			1
transect soil n	C	O	whitford			1
transect soil physics - cations	C	O	whitford			1
transect soil physics - ph	C	O	whitford			1
transect soil physics - phosphate	C	O	whitford			1
transect soil physics - soil analysis	C	O	whitford			1
transect soil po4-p	C	O	whitford			1
transect soil total nitrogen	C	O	whitford			1
transect soil water potential	C	O	anderson			1
transect soil water potential - raw	C	O	anderson			1
transect termite data	C	O	whitford			1
upper trailer soil temperatures	C	O	whitford			1
ammonia volatilization from ... habitats	C	O	schlesinger/peterjohn	Y	Y	2
hydrology natural runoff plots - runoff	C	O	ward	Y	Y	2
hydrology natural runoff plots h2o chemistry	C	O	schlesinger	Y	Y	2
hydrology plant cover	C	O	anderson			2
nitrogen volatilization from grassland soils	C	O	schlesinger/peterjohn	Y	Y	2
small mammals consumer plots	C	O	whitford/lightfoot	Y		2
transect biomass - forbs & grasses	C	O	whitford			2
nitrogen and phosphorus chemistry	C	O	schlesinger	Y	Y	3
summary of grassland nitrogen and phosphorus	C	O	schlesinger	Y	Y	3
summary of intershrub nitrogen and phosphorus	C	O	schlesinger	Y	Y	3
summary of shrub nitrogen and phosphorus chem	C	O	schlesinger	Y	Y	3
ibp bajada/playa soil temperatures	C	O	whitford			I

STUDY	S	A	P.I.	DD	DS	O
ibp bajada/playa soil water potentials	C	O	whitford			I
ibp larrea litter data	C	O	ludwig			I
ibp precipitation	C	O	whitford			I
ibp prosopis litter data	C	O	ludwig			I
ibp prosopis/larrea litter data - summary	C	O	ludwig			I
ibp soil water potential	C	O	whitford			I
ant nest soil nutrients	C	O	di marco/whitford			R
ant nest soil organic matter	C	O	di marco/whitford			R
ant nest soil water content	C	O	di marco/whitford			R
arthropod species composition	C	O	lightfoot/whitford			R
arthropod trophic group composite	C	O	lightfoot/whitford			R
density and cover of winter annual plants	C	O	di marco/whitford			R
fluffgrass anion exchange resins bags for no3	C	O	silva/whitford			R
fluffgrass cation exchange resin bags for nh4	C	O	silva/whitford			R
fluffgrass mesocosm microarthropod numbers	C	O	silva/whitford			R
fluffgrass mesocosm: mites and nematodes	C	O	silva/whitford			R
fluffgrass plant dynamics	C	O	silva/whitford			R
fluffgrass plant growth	C	O	silva/whitford			R
fluffgrass plant total nitrogen	C	O	silva/whitford			R
fluffgrass rhizosphere nitrogen mineralization potential	C	O	silva/whitford			R
fluffgrass soil nitrogen	C	O	silva/whitford			R
fluffgrass soil total nitrogen	C	O	silva/whitford			R
jornada grasshopper data	C	O	lightfoot			R
jornada grasshopper plot vegetation data	C	O	lightfoot			R
larrea leaf nutrients	C	O	lajtha			R
post fire nitrogen mineralization potential in boer in jun	C	O	cornelius			R
post fire nitrogen mineralization potential in boer in oct	C	O	cornelius			R
post fire nitrogen mineralization potential in prgl in jun	C	O	cornelius			R
retranslocation data for larrea leaves from fert. plots	C	O	lajtha			R
transect microarthropod counts	C	O	cepeda			R
water/nutrient effects on larrea leaf	C	O	lajtha			R
water/nutrient effects on leaf longevity	C	O	lajtha			R
animal transects	C	R	whitford/lightfoot	Y		2
arthropod pitfall traps - lter-ii	C	R	whitford/lightfoot	Y		2
small mammal trapping (lter-II)	C	R	whitford	Y		2
soil nutrient distribution in long-term NPP plots	C	R	virginia/jarrell	Y		2
biomass removal	C	R	huenneke	Y		3
bird survey	C	R	huenneke	Y		3
erosion zone vegetation	C	R	huenneke	Y		3

JORNADA LTER DATA REQUEST LOG

SentBy: JA = John Anderson   KL = Kevin La Fleur   BN = Barbara Nolen
LH = Laura Huenneke   WB = web client retrieved   KR = Ken Ramsey
Format: D=diskette   E=email   F=ftp   H=hardcopy   W=World Wide Web

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 Ohio St. Univ.	Transect Plant Line Intercept OCT82, OCT83, SEP84	FALL.DAT	395	D	KL
JA	10/21/94	10/21/94	Ted Floyd Penn St. Univ.	Monthly air(min,max,avg), precip Apr-Aug 93 & 94	WSDAYAL.DBF	2	E	JA
JA/KL	10/20/94	10/25/94	Leslie Sieger Colorado St. Univ.	Jornada LTER keyword listing Jornada bibliography		125 191	E E	KL KL
JA	11/21/94	11/21/94	Kay Gross KBS	Jornada LTER plant species list Listing: alpha and family		114	E	JA
JA	01/10/95	01/10/95	Mike Atchley	Air temp & precip Jun-Sep 92-94		10	D	JA
JA	01/30/95	02/06/95	Kirk Maloney Iowa State Univ.	Jornada bibliography	JRNLTER	191	F	JA
JA	01/31/95		Ben Sherman University of WI	Jornada bibliography [Waiting for Sherman response on file format and destination]				
KL	02/03/95	03/14/95	Debbie Hartell Holloman AFB	USDA/NOAA evap pan 1962-1974	EVAP6274.DAT EVAP6274.HIS	220	D	KL
JA	03/07/95	03/07/95	Chris Tripler Idaho St. Univ.	Jornada bibliography	JRNLTER	191	E	JA
JA	03/14/95	03/14/95	Jeff Straka Iowas St. Univ.	Jornada playa invertebrate citations		3	E	JA
JA	04/03/95	04/04/95	Judith Lancaster Desert Research Institute Univ of NV	Pub: LTER in the U.S. - A Network of Research Sites 1991	NA	NA	H	JA
JA	04/28/95	04/28/95	Keith Killingbeck Univ of RI	Precip for U.T. (85-95) & C-CALI (89-95)	JRN_SUM.DAT TERMCALI.ORG	26	D	JA
JA	05/15/95	05/16/95	Sarah Valentine McBeans@io.com	Jornada LTER plant list		61	E	JA
JA	05/19/95	05/29/95	Ben Sherman ben@allstenex.botany.wisc .edu	Jornada bibliography	JRNLTER2	182	E	JA
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) Monthly summary: rain,temp,evap	CDNOAA-E.DAT	77	E	JA
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 Pipeline Safety Dept.	50cm&100cm soil temp for 84,85,94,95 for Jun-Sep for each year.	WSHOURAL.DBF	430	D	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, GRAV,BASN,SUMM)	jrn_npp.dat	26	F	JA
JA	04/29/96	04/29/96	Jan Hendricks	Jornada bib citations (H2O&nutrient)	jrnbib	26	E	JA
JA	05/19/96	05/20/96	Tom Crist/Carl Friese	Jornada bib citations (C,N,&P)	jrnbib	26	E	JA
JA	07/19/96	07/25/96	John Frey(UNM)	USDA standard rain gage network data	usdacan.exe	2631	E	JA
JA	09/10/96	12/09/96	Christine Mann(Ft.Collins)	Thermocouple temp(air,1,5,10,20,50, 100,200 cm)	wshoural.dbf	7553	F	JA
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	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	03/19/97	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
JA	10/30/97	11/04/97	LeRoy Rodgers	1997 Annual Report	n/a	n/a	H	JA
JA	03/31/98	04/20/98	Tamara Hockstrasser	CDRRC std can precip (1936-1997) [Delay in receiving data from CDRRC]	cdrrcpcp.dbf	10	E	JA
JA	04/28/98	04/28/98	Dale Medford	Web-retrieved soil temperature data	WSDAY95.DAT	44	W	WB
JA	04/28/98	04/28/98	Dale Medford	Web-retrieved soil temperature data	WSDAY96.DAT	44	W	WB
JA	04/28/98	04/28/98	Dale Medford	Web-retrieved soil temperature data	WSDAY97.DAT	44	W	WB
JA	04/28/98	04/28/98	Dale Medford	Web-retrieved soil temperature data	WSDAY98.DAT	22	W	WB
JA	05/08/98	05/08/98	Meli Mandujano	LTER WS air temp & rain 1996	WSDAY96.DAT	44	W	JA
JA	05/08/98	05/08/98	Meli Mandujano	LTER WS air temp & rain 1997	WSDAY97.DAT	44	W	JA
JA	05/08/98	05/08/98	Meli Mandujano	LTER WS air temp & rain 1998	WSDAY98.DAT	25	W	JA
JA	10/13/98	10/13/98	Giora Kidron, NMSU	Precipitation detail, LTER W.S.	WSPRECDT.DAT	116	E	JA
JA	12/14/98	12/14/98	Anne Hartley	NPP site GRG precipitation data	NPP_GRG.DAT	70	W	JA
JA	01/04/99	01/04/99	Giora Kidron, NMSU	Precipitation detail, Oct-Dec1998	WSPRECDT.DAT	11	E	JA
JA	08/16/99	08/16/99	Joe Hirscher, NMSU Biology	NPP site GRG precipitation data	NPP_GRG.DAT	83	E	JA
JA	11/08/99	11/08/99	Paolo D'Odorico,TX A&M	Transect soil water content data	all years	2844	W	JA
JA	11/22/99	11/22/99	Giora Kidron, NMSU	Precipitation detail, Oct-Dec1998	WS99PREC.TXT	13	E	JA
JA	11/24/99	12/01/99	Madhur Anand (UNM)	Transect Plant Line Intercept LTER series (field data) all years	LTERwkC.DAT	3850	F	JA
JA	11/29/99	11/29/99	Peg Gronomyer (non-LTER)	LTER WS 1991 precip & mx & mn air	WSDAY91.DAT	45	W	JA
JA	11/29/99	11/29/99	Peg Gronomyer (non-LTER)	LTER WS 1992 precip & mx & mn air	WSDAY92.DAT	45	W	JA
JA	11/29/99	11/29/99	Peg Gronomyer (non-LTER)	LTER WS 1993 precip & mx & mn air	WSDAY93.DAT	45	W	JA
JA	11/29/99	11/29/99	Peg Gronomyer (non-LTER)	LTER WS 1994 precip & mx & mn air	WSDAY94.DAT	45	W	JA
JA	11/29/99	11/29/99	Peg Gronomyer (non-LTER)	LTER WS 1995 precip & mx & mn air	WSDAY95.DAT	45	W	JA
JA	11/29/99	11/29/99	Peg Gronomyer (non-LTER)	LTER WS 1996 precip & mx & mn air	WSDAY96.DAT	45	W	JA
JA	12/02/99	12/03/99	Madhur Anand (UNM)	Transect Plant Line Intercept LT series (% cover) all years	LTweekC.DAT	3200	F	JA

Jornada Basin LTER IV: Linkages in Semi-arid Landscapes

I. Overview

The overall goal of the Jornada Basin LTER program is to identify the key factors that control ecosystem dynamics and biotic patterns in Chihuahuan Desert landscapes. These landscapes exemplify the ecological conditions, vulnerability, and management issues found in semi-arid landscapes around the globe. Jornada work has up until now focused primarily at the scale of a single plant-interspace and on the dynamics of plant assemblages within a site. We are committed to scaling up this understanding to the patch, landscape, and region so that we can address the questions of primary importance in semi-arid regions worldwide: desertification; remediation and management; and the interactions between deserts and other regions of the changing global system. The Jornada Basin LTER program and the Jornada Experimental Range (USDA-ARS) have brought unique resources to bear on these questions in the past two decades. We describe here the key long-term data sets and experiments, and shorter-term efforts, by which we propose to integrate the progress we have made to date, and the steps we plan toward a more sophisticated understanding of semi-arid ecosystems. Our approach emphasizes the importance of landscape fluxes of water, nutrients, and organisms to understanding ecosystem dynamics at multiple spatial scales.

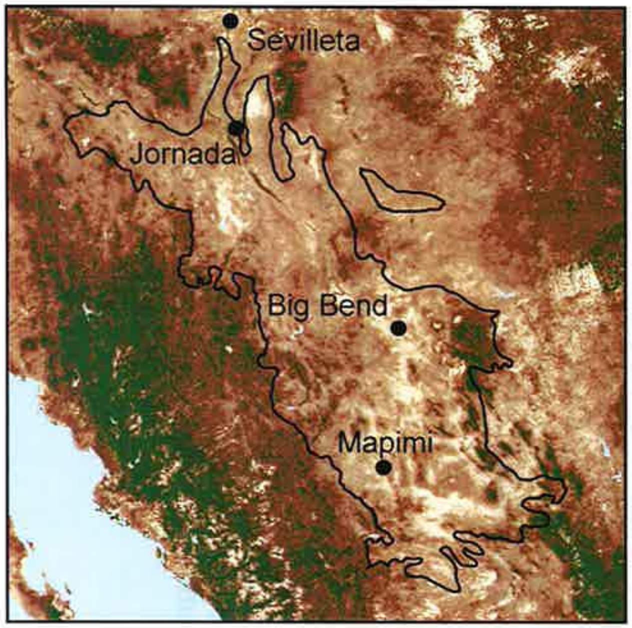
II. Introduction: Semi-arid Ecosystems and Desertification

A third of the earth's land surface is arid or semi-arid in climate, with drylands occurring on all continents and constituting an important though challenging environment for human activity. Human populations and the intensity of development and utilization/exploitation are increasing rapidly in many of these regions, changing the way in which people interact with the unique biological diversity of desert systems (Huenneke and Noble 1996). Meanwhile, past management actions and climatic fluctuations have caused degradation of many of these ecosystems (desertification). The potential exists for further dramatic shifts in biota and ecosystem function in the future under directional changes in climate and as a result of changes in landuse and management practices. These changes may result in further desertification on some sites and remediation on others (Schlesinger et al. 1990; Herrick et al. 1997; Huenneke in press; Havstad et al. 2000; Peters and Herrick submitted). The Jornada Long-Term Ecological Research program is dedicated to understanding the causes and consequences of change in the structure and function of Chihuahuan desert ecosystems. **In particular, our goal is to identify the key factors that control ecosystem dynamics and biotic patterns at the landscape scale.** Our scientific program acknowledges the influence of human presence and activities on the ecological processes acting within arid lands. Our further objective is to provide a scientific basis for the development of applications aimed at improving the sustainability of these ecosystems.

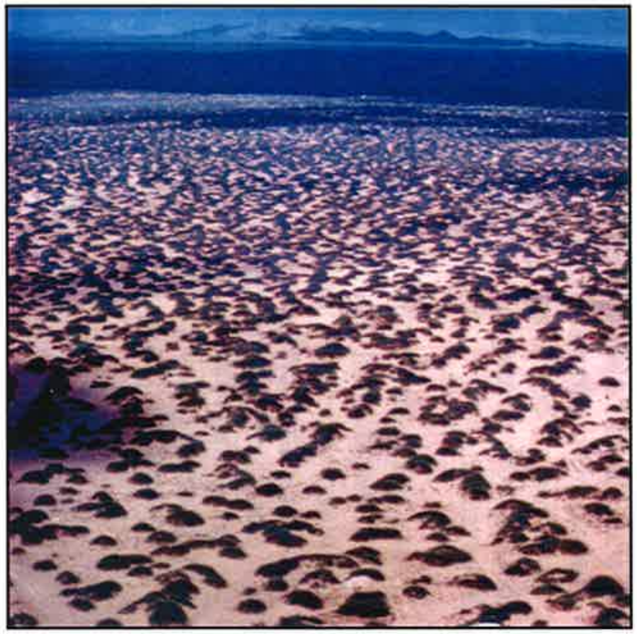
Resource Redistribution Model of Desertification

For the past two funding cycles, our primary scale of interest has been the scale of individual plants and the interspaces between them. Our conceptual framework has been the resource-redistribution model of desertification (Fig. 1.1) – the idea that

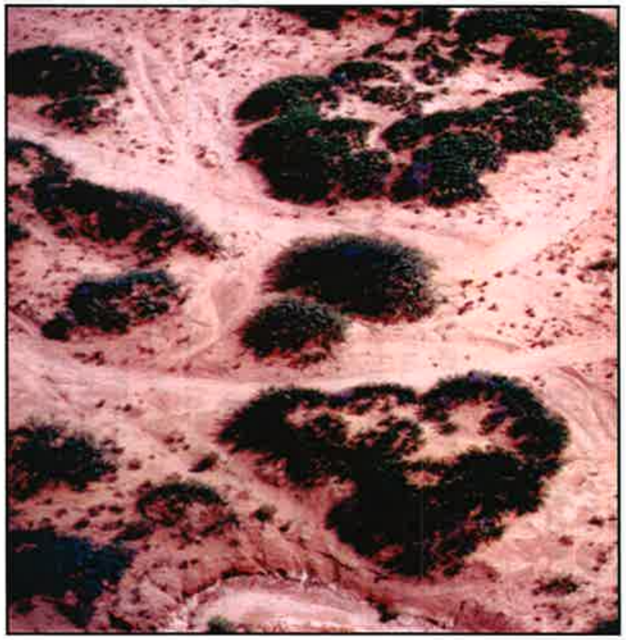
- perturbations (whether by drought, overgrazing, or other disturbance) create openings that lead to the redistribution of soil resources by abiotic forces (wind, water);
- openings in the grassland community and the redistribution of resources create conditions favorable to the establishment of desert shrubs; and



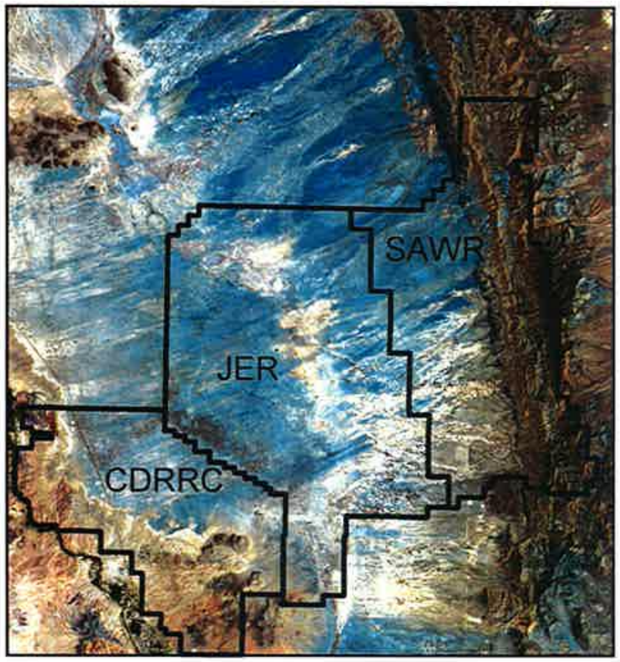
e. AVHRR bands 1,2,3
1: 15000000



b. Oblique aerial photograph
1:600



a. Oblique aerial photograph
1:150



d. Landsat TM, bands 1, 2, 3
1:400000

c. True color aerial photograph
1:900

Figure 2.1. Scaling up.

- the presence of shrubs exacerbates this redistribution of resources in such a way as to perpetuate the shrub-dominated state (Schlesinger et al. 1990).

Our empirical and modeling efforts have focused on understanding the mechanisms of redistribution within sites, particularly aeolian fluxes and surface hydrology, and the consequences to heterogeneity of soil resources that are so critical for plant growth and ecosystem function. We have established that shrubs facilitate the collection of water, organic matter, and other nutrients at their bases, and that intershrub areas (especially in mesquite dunelands) are locations in which resource redistribution is most frequent and intense. We have explored these plant-scale patterns and processes within each of the most widespread of Chihuahuan desert ecosystems by establishing a network of 15 sites (the NPP network) representing 5 major non-riparian vegetation types of the Jornada basin: black grama grasslands, creosotebush, mesquite, tarbush, and playas. Our comparisons among these sites confirm that plant-scale processes and within-site dynamics vary among ecosystems.

Importance of Multiple Scales

Although our short- and long-term studies have explored many of the potentially important features and drivers in this landscape, important gaps remain in our understanding. The extreme temporal variability of semi-arid ecosystems, together with significant lags and 'pulse-reserve' ecosystem responses (Noy-Meir 1973), make it quite difficult to capture ecosystem dynamics in short-term experiments. Other characteristics of desert ecosystems, including short, intense rain and wind events combined with topographic and edaphic variation, result in the redistribution of soil and nutrients across the landscape. We expect that landscape position and movements of resources and organisms among sites may explain much of the unresolved variability observed within sites. For example, NPP estimates from three black grama grassland sites showed as much variation among sites in 1994 as the variation among grassland and shrubland sites in that same year (Fig. 1.4). This high temporal and spatial variation inherent in desert landscapes requires that we understand how the various components of the landscape interact if we are to meet our goal of understanding the causes and consequences of change in Chihuahuan Desert ecosystems. Improved understanding of these systems will require us to work at multiple spatial scales, from that of a single plant-interspace (Fig. 2.1a), to the patch (assemblage of multiple plants and interspaces; Fig. 2.1b), landscape unit or ecological range site consisting of multiple patches (Fig. 2.1c), landscape comprising multiple sites, such as the Jornada Basin (Fig. 2.1d), and finally to the regional scale (Fig. 2.1e). Corresponding to these spatial scales are temporal scales that generally decrease in frequency as the spatial scale increases. Because of this relationship between time and space, our discussion will be limited to spatial scales and temporal scaling will be implicit.

We recognize that these spatial scales are arbitrary, that a continuum of scales likely exists, and that a different set of scales could have been defined. We selected these scales for several reasons that build upon our previous work conducted at the plant-interspace scale. First, vegetation patches are the next logical scale beyond plant-interspaces and, along with landscape units, are the entities exploited by human activity and targeted for management or remediation activities. Understanding ecosystem dynamics at these scales is thus critical in generalizing our results to semi-arid and arid systems in other regions. Second, fluxes between landscape units are potentially critical in explaining the dynamics of a single landscape unit. Past experience has shown that our point-based understanding of dynamics within a site does not completely explain the condition and dynamics of that site. It is our working hypothesis that landscape position and linkages with other landscape units (e.g., run-on moisture supply, aeolian transport or propagule

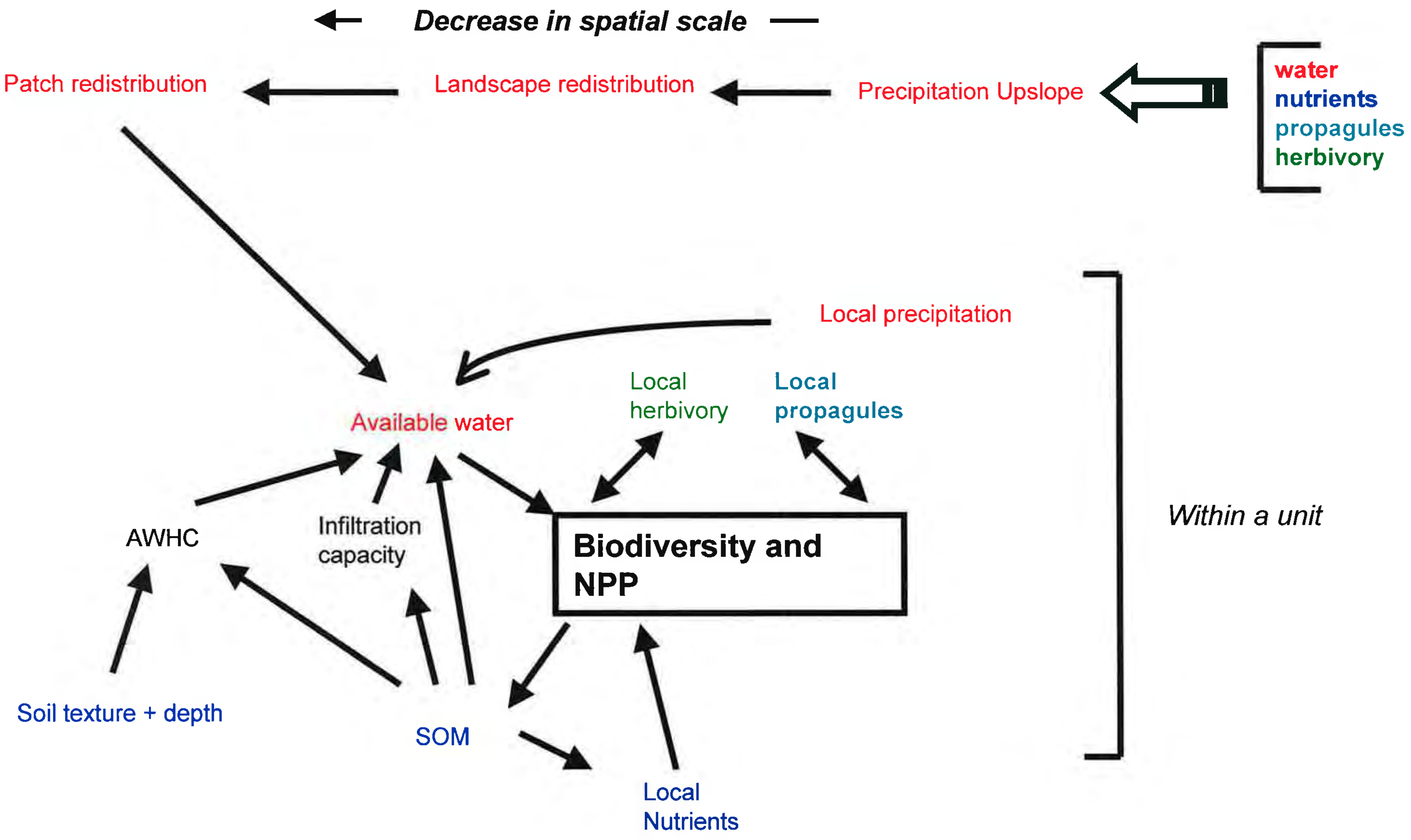


Fig. 2.2 Conceptual model of flows of materials within and among landscape units. Water, nutrients, propagules, and herbivory are spatially distributed across the landscape, and contribute to localized inputs within each landscape unit. Redistribution of water is shown as an example. Within a landscape unit, these materials exert controls on biological processes that influence patterns and dynamics in biodiversity and NPP.

movement) exert important influences on the dynamics of a single site. Third, desertification and other substantial alterations in the structure and function of semi-arid ecosystems have the potential to influence the environment on a global scale – through dust generation, changes in albedo or in evapotranspiration, and so on. It is the integration of transport and flux processes over the entire Jornada basin that interacts potentially with other regions, and contributes to global dynamics. Hence it is critical that we be able to integrate current processes across the entire basin, and that we extend our basin-scale understanding through time – into past and future climatic and biotic regimes.

III. Conceptual Framework

Our overarching model is based on the intrinsic characteristics of semi-arid ecosystems, particularly the importance of short intense precipitation events in landscapes containing substantial topographic and edaphic variability. **Our central hypothesis is that landscape position and linkages among landscape units exert important influences on ecosystem dynamics and biotic patterns within sites.** Thus our conceptual framework includes processes and dynamics within each spatial scale as well as interactions and fluxes among scales (Fig. 2.2). The goal of our proposed work is to determine the relative importance of within and between unit interactions to the patterns in vegetation and soil properties observed at each scale. Our conceptual framework begins with the plant-interspace as the smallest scale of interest (Fig. 2.3). Although we will also study finer-scale processes, such as leaf-level physiology, the fundamental unit of interest is an individual plant and its associated interspace. Because the focus of our previous LTER efforts has been at this spatial scale, we have a wealth of information to characterize the processes and redistribution of materials between plants and interspaces. Even at this scale, gaps in our knowledge remain, and we will initiate new experiments to provide information needed to translate to larger scales.

Our next scale of interest is the assemblage of similar plants and interspaces into patches (Fig. 2.3). At the Jornada, most patches are dominated by any one of several species of shrubs (mesquite, creosotebush, tarbush) and grasses (black grama and tobosa). These patches vary in size from several individual plants (< 5 m^2) to several hundred individuals (> 100 m^2). The next scale, the landscape unit (roughly equivalent to an NRCS ecological site), consists of a number of interacting patches. For example, redistribution of seeds by rodents within and between patches can be very important in generating and maintaining biodiversity at this scale. Spatial variation within the landscape unit, such as small depressions, can collect water and nutrients to result in this patchiness in soils and vegetation. Important landscape units at the Jornada are bajadas, sandy basins, and playas. Some of the effort of LTER I dealt with this spatial scale, and provided us with a better understanding of controls on structure and function within each unit. The ecological site is also the unit typically of most interest for management. The Jornada basin consists of the collection of these interacting landscape units. Although transfers of water and nutrients occur between landscape units, especially following intense rain or wind events, these fluxes have not been measured, despite their expected importance to observed patterns in vegetation and soils. The largest spatial scale considered here, the Chihuahuan desert region, consists of a collection of areas comparable to the Jornada basin that includes a number of research sites (Big Bend, Texas; Mapimi, Mexico; and the Sevilleta National Wildlife Refuge - LTER). This region experiences similarities as well as differences in weather, and the land-atmosphere interactions surrounding one site can potentially affect regional weather patterns at nearby sites. The region is the scale at which the most important global interactions are expected, such as contributions to carbon sequestration and elevated concentrations of atmospheric CO_2.

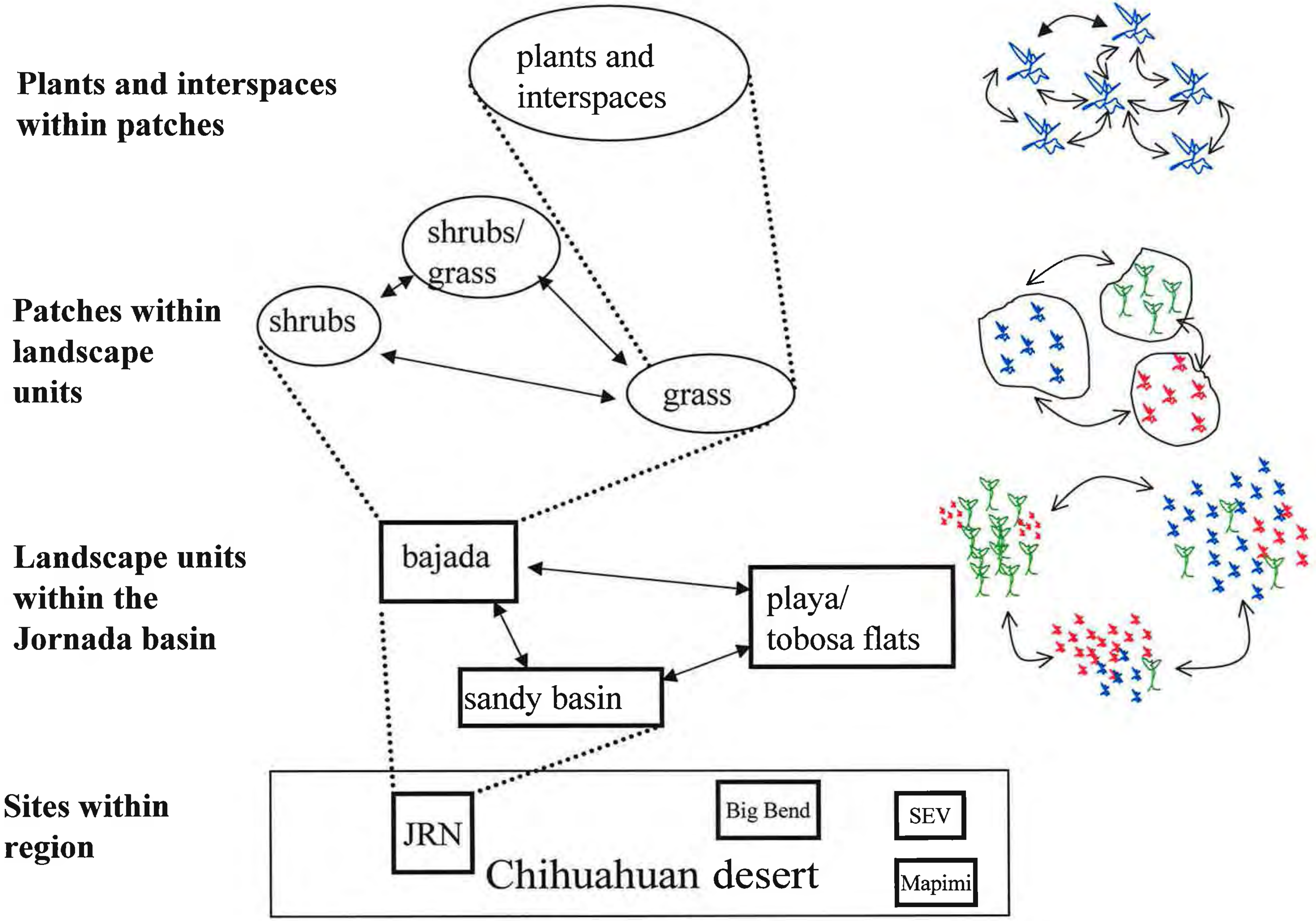


Fig. 2.3 Conceptual model showing scaling from plants and interspaces to patches, landscape units, the Jornada basin, and the region.

Land use and management practices as well as suburbanization are also expected to be important at this scale.

We propose to make this logical progression to investigate the implications of redistributions at the plant-interspace scale, where much of our previous work has focused, for larger spatial scales. We will also work at the scale of the entire basin and the region, but with less concentrated effort. We will organize our research around 15 existing sites that capture the spatial variation of the landscape within the Jornada basin. This network of NPP sites was established in 1989 to provide the setting for comparative studies of the non-riparian ecosystem types of the Jornada basin: black grama grasslands, creosotebush shrublands, mesquite dune sites, tarbush flats, and playas. There are three sites associated with each vegetation type because of the spatial variation in topographic position, soils, and vegetation within each type. These sites are located throughout the basin (Fig. 2.4) and represent examples of landscape units within our conceptual framework (Fig. 2.1c, 2.3). A variety of data collected at these sites at regular intervals forms the basis of our integration efforts. Aboveground biomass and NPP by species, plant phenology, soil water content, precipitation, ground-dwelling arthropods, reptiles, and amphibians are currently being monitored at each site as part of our long-term studies. Although the NPP sites provide one of the most important existing data sets for examining the role of landscape position and fluxes among landscape units in influencing ecosystem dynamics, these aspects have not yet been examined in a critical way or evaluated relative to the importance of within-landscape unit processes. Furthermore, these data have not been fully synthesized and integrated with data sets collected on other components of Chihuahuan desert ecosystems or collected from other locations within the Jornada basin.

IV. Proposed Work for LTER IV (2000-2006)

We have two major objectives for the coming phase of the Jornada Basin LTER program: (1) **to synthesize and integrate existing short- and long-term datasets in a landscape context**, and (2) **to investigate landscape fluxes of water, nutrients, and organisms in order to evaluate key processes affecting ecosystem dynamics and responses at this scale**. Both efforts are crucial to our ability to understand the two key issues regarding human interactions with semi-desert ecosystems: desertification and remediation.

Our basic approach is to structure a more interactive and iterative process of multi-scale analysis of the many sources of Jornada data, supplemented by collection of additional data in key areas and by simulation modeling. We intend not only to achieve understanding of key processes at larger spatial scales than previously studied, but also to energize a synthetic integration of multiple processes that until now have been studied in isolation. To maximize this integration, we will organize our research around the existing NPP network of 15 sites in 5 different ecosystem types. We will also employ remote sensing techniques to provide information critical to assessing fluxes and processes at our larger scales of interest. Although mechanistic and process studies at the plant-interspace and the regional scale will continue, our primary focus will be on dynamics within landscape units and on the connections among landscape units in the Jornada Basin – scales “c” and “d” in our hierarchy of scales (Fig. 2.1).

Our ongoing studies at the NPP sites will provide information relevant to within-landscape unit variation, such as the role of patches within these units. We will supplement these studies with significant new work designed to address fluxes of materials among landscape units in an attempt to understand variation among NPP sites with similar vegetation. We will also maintain other long-term studies located in various parts of the basin because of their importance in understanding basin-level properties and processes. These studies also allow experimental

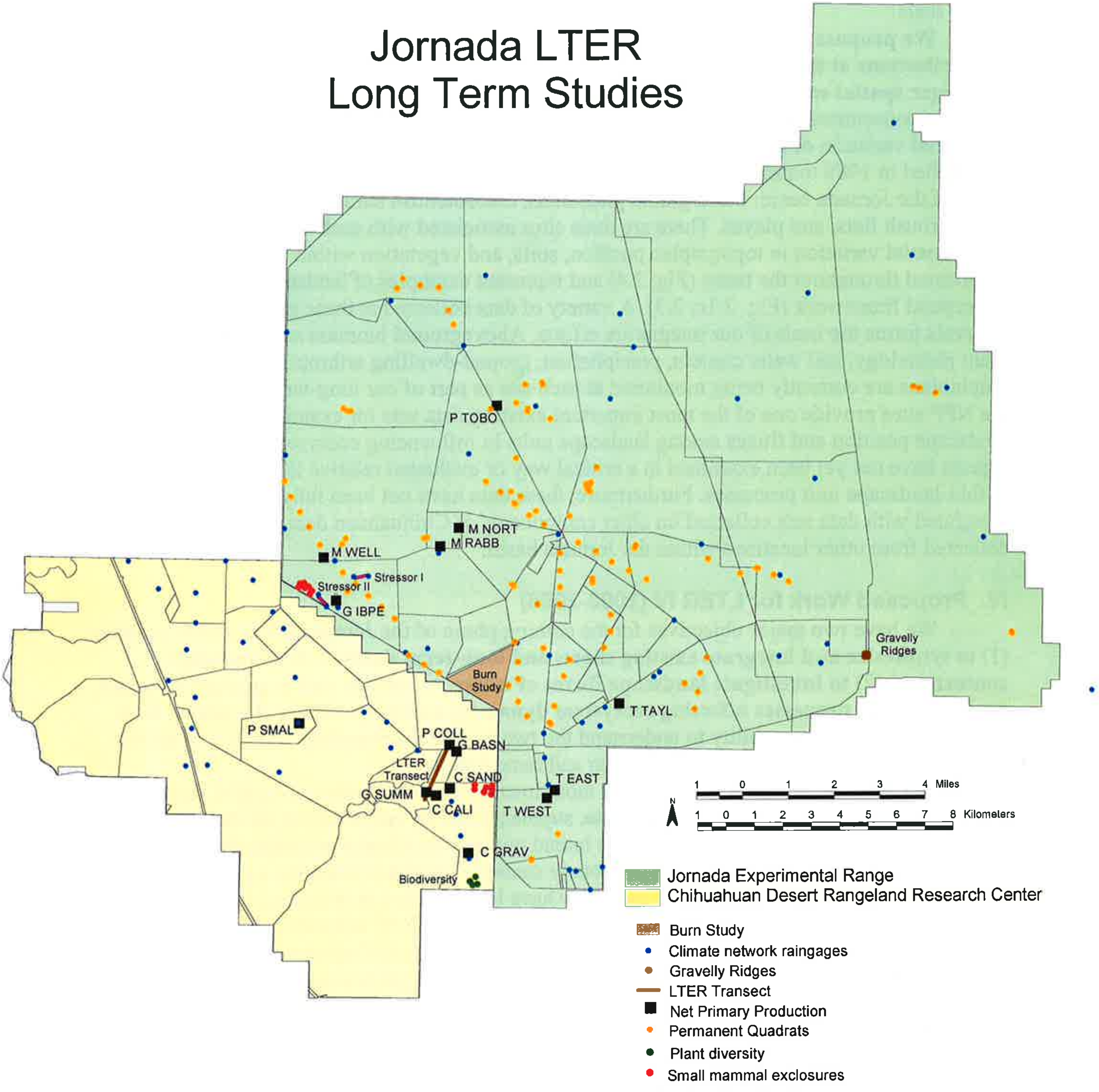


Figure 2.4. Long term studies.

manipulations that we are unable to conduct within the intensive study sites. We will use simulation modeling to synthesize and integrate data collected from the short- and long-term experiments in order to elucidate the key processes affecting ecosystem dynamics at different spatial scales. For example, we will use the spatially-explicit ECOTONE model of vegetation, soil water, and nutrient dynamics to generate testable hypotheses about the relative importance of different processes to these dynamics at different spatial scales. This exercise will lead to new field experiments directed at specific aspects of Chihuahuan desert ecosystems. We will also use the model to make predictions about future changes in these systems as the environmental drivers change (e.g., climate, management practices, and land use).

A. Long-term experiments and core data sets

The following long-term studies and experiments represent the major Jornada efforts most closely related to the themes of this proposal; Table 1.2 presents a more complete list of datasets from all Jornada LTER studies. Table 2.1 summarizes the ecosystem types being studied and the data being collected; Fig. 2.4 is a map showing the location of primary long-term study sites across both the USDA-Jornada Experimental Range (JER) and the NMSU research area (Chihuahuan Desert Rangeland Research Center or CDRRC). We give only brief descriptions of methods here, and refer the reader to detailed documentation for each project and dataset available through the Jornada LTER web site (*http://jornada.nmsu.edu*). Because of the importance of the NPP sites to our proposed research, we first describe all studies being conducted at these sites, followed by additional ongoing long-term studies that will be critical to meeting our objectives. The original "core areas" of the LTER research program are all addressed by ongoing work at the Jornada, though we do not organize our list in those terms.

Net Primary Productivity Patterns. The network of long-term intensive study sites is useful for the landscape scale of study in part because the three sites per ecosystem type were explicitly chosen to represent the range of variability (e.g., in plant size and density) within a type. Aboveground plant biomass and production are being estimated by species for each site in order to assess the heterogeneity in Chihuahuan desert ecosystems over time and space. Long-term records of biomass and production in these sites provide the baseline for documenting differences among ecosystem types in response to environmental variability (primarily weather). Grids of permanent quadrats in each site are sampled three times annually for aboveground volume of each vascular plant species. Based on species-specific regressions, these data are used to estimate biomass at each date, and positive increments of aboveground biomass for a species in a quadrat between dates are used to estimate net primary production for that interval (Huenneke et al. in review). Our results demonstrate that mean aboveground NPP does not vary substantially among ecosystem types, though the seasonality and the interannual variability of production do differ greatly (Huenneke 1996). In general terms, grasslands demonstrate higher production later in the year, and greater interannual variation, than do shrub-dominated systems (Fig. 1.4); spatial heterogeneity, though, is usually greater in shrublands.

Plant phenology at NPP sites. The reproductive status (dormant, vegetative, bud, flower, fruit) of individuals of perennial grasses, shrubs, and succulents has been monitored monthly since 1992 along permanent transects at each site. Results indicate large variation among species in timing and frequency of reproduction as well as large inter-annual variation within species. These data constitute information on the variation in sensitivity to climatic factors among species within a growth form, and on the relationship between climatic drivers and plant recruitment processes. This study will be supplemented with work assessing the availability of propagules within landscape units and the dispersal of seeds among units.

Table 2.1. Selected long-term investigations in the Jornada Basin LTER program.

Study	Ecosystems	Data Sets
NPP	C, G, M, P, T (3 sites each)	Aboveground plant biomass by species, 3x yearly, and ANPP by species, 3 intervals per year, 1989 – present
Plant phenology	C, G, M, P, T (NPP sites)	Reproductive state of individuals of perennial plant species, by month, 1992 - present
NPP soil water	C, G, M, P, T (NPP sites)	Neutron probe readings of soil water content, by depth, 5 pairs of access tubes per site (under plant vs interspace), monthly, 1989 - present
Transect soil water	C, G, P (LTER I transects)	Neutron probe readings of soil water content, by depth, at 30 m intervals along 3 km topographic gradient, monthly, 1982-present
Transect vegetation	C, G, P (LTER I transects)	Perennial plant cover by species, 30-meter line intercepts, at 30 m intervals along 2.7 km topographic gradient, semiannually 1982-88, 5 yr intervals since then
Fenceline vegetation	C, G, P (LTER I transects)	Perennial plant cover by species, 30-meter line intercepts, at 30 m intervals, crossing fenceline between LTER exclosure and pasture, on topographic gradient, late summer, at 5 yr intervals, 1982 – present
NPP arthropods	C, G, M, P, T (NPP sites)	Ground-dwelling arthropods sampled in pitfall traps, 4x annually, 1989-present; since 1994, in separate pitfalls from herp sampling
NPP herps	C, G, M, P, T (NPP sites)	Reptiles and amphibians sampled in pitfall traps, 4x annually, 1989-present
Multiple stressor experiment	G, M (2 sites)	Perennial cover by species, 70 m line intercepts, prior to initation in 1997, since then at 3-year intervals; small mammals; soil C and N prior to initiation, repeat in 2000
Small mammal exclosures	C, G (2 sites; also SEV, Mapimi)	Plots excluding livestock, lagomorphs, or rodents; ants, plants, grasshoppers, disturbance monitored 2x times annually; small mammals monitored in adjacent webs
Plant diversity experiment	C	Eight treatments involving plant species or functional group removals, in 25 m x 25 m plots; 6 replicates of each treatment; vegetation, soil erosion, nutrient cycling
Fire study	G, M	400-ha pasture burned; pre- and post-fire data on shrub size and density, plant species composition
JORNEX	C,G,M	Multiple-sensor aerial and ground-based imagery
JER Quadrat Data	All	Grass basal area, forb species and density, canopy area of shrubs and suffrutescents, 1 m^2 permanent quadrats established 1915 - 1932, sampled annually through 1947, intermittently since then, relocated/geopositioned in 1995
Gravelly Ridges	C	Perennial cover by species, 10.6 m line intercept, (original 1938 methods maintained); 1938, 1947, 1956, 1960, 1967, 1989, 1995, now at 5 year intervals

Soil water at NPP sites. Soil water content has been measured monthly by depth at each site since 1989 using 5 pairs of neutron probe access tubes. Measures of soil water content represent both precipitation inputs as well as redistribution of water across the landscape; these two sources of water have not been differentiated. Observed differences in NPP between sites within each vegetation type are expected to be related to the relative importance of overland flow and precipitation. Our efforts to date have focused on precipitation inputs and local redistribution between plants and interspaces. Future studies will include the redistribution of water across the landscape following rain events.

Consumers at NPP sites. Invertebrates are by far the most diverse and abundant group of consumers in each of the five ecosystem types at the Jornada. Arthropods lend themselves to ecological study because of the large numbers of taxa and of individuals, the variety of trophic groups represented, and the wide range of ecological specializations among taxa. Additionally, arthropods are relatively easy to sample with adequate replication of experimental and sample units. Arthropod populations also respond much more quickly to environmental change than vertebrates because of their short life cycles and good dispersal abilities. Over the past 10 years, we have documented the taxonomic composition of ground-dwelling arthropods at each NPP site with pitfall trap sampling (note: playas are not sampled, as pitfall traps are not practical in systems so vulnerable to flooding). We have also documented the response of various taxonomic and trophic groups to environmental change. Termites are not included because they were extensively studied in LTER I-III (e.g. Nash and Whitford 1995).

We also monitor the species composition and populations of lizards at each site. Lizards are relatively abundant vertebrate predators, and provide us with useful data on the relationships between aboveground NPP, primary consumers (arthropods), and second-order consumers. Rodent and rabbit species composition and densities are monitored in the creosotebush and black grama grassland ecosystem types as part of the Small Mammal Exclosure Study project (see below). By integrating long-term data on consumers with vegetation, weather, and soil water from the same sites, we expect to elucidate relationships among these important influences on ecosystems within landscape units. Thus, these long-term trends and relationships will provide the baseline for investigating the importance of animal-mediated fluxes among landscape units.

Small Mammal Exclosure Study. We are experimentally manipulating rabbits and rodents to evaluate their effects on various aspects of Chihuahuan desert ecosystems, including plant species composition and diversity, seed harvester ant, termite and grasshopper populations. This work is part of a cross-site study initiated in 1995 through an NSF TECO award; similar study designs are in place at the Sevilleta National Wildlife Refuge-LTER and the Mapimi Biosphere Reserve, Mexico. Exclosures constructed with different fencing materials for rabbits, rodents, and cattle were located on a creosotebush shrubland and black grama grassland at the Jornada. Within each plot, vegetation is measured for height and canopy cover by species twice each year, and ants, termites, and grasshoppers are inventoried semi-annually or annually. Digging activities by animals are also documented. Rodent populations are sampled from each of three webs at each study site twice each year. Rabbit densities are estimated from road transect surveys near each study site four times each year. Rabbit pellets are counted and removed from each vegetation quadrat, and provide a relative measure of rabbit activity in each control plot. Analysis of these vegetation data with rodent and rabbit densities is providing valuable information on the role of small mammals and rodents in influencing vegetation structure and dynamics, both for two vegetation types at the Jornada, and more broadly for the Chihuahuan desert through the cross-site comparisons. This study will continue at the Jornada and Sevilleta as part of each LTER effort, and at Mapimi as separate funding permits. We expect these data will provide important information on both within-site and regional variation in relationships between small mammals, rodents, and vegetation structure and dynamics.

Transects of LTER I. The centerpiece of the first phase of the Jornada LTER program, these 3-km transects run along a topographic gradient from the grassland belt at the base of a rocky mountain slope through bajada creosote shrubland and basin grassland to a small playa. Vegetation was monitored monthly with 30-m line intercepts perpendicular to the transects at 30-m intervals, and with photo plots at 2-wk intervals, for the first 6 years of study. Fertilization of one transect annually with nitrogen homogenized soil resource availability, enhanced above-ground production, and altered plant species composition (Cornelius and Cunningham 1987). Currently the line intercepts are sampled every 5 years; similar sampling monitors the fencelines of the large exclosure to compare livestock-grazed and post-exclosure ungrazed vegetation. Though replication is poor, data from these transects have value for examining the role of landscape (topographic) position for processes within specific ecosystem types (Wondzell et al. 1996). For example, comparisons of plant production between fertilized and unfertilized transects suggest a redistribution of nitrogen through time from upslope to downslope. Soil water has been monitored since 1982 every 30 m along the transect (Nash et al. 1991).

JORNEX. Remote sensing data have been collected on a regular basis at the Jornada Experimental Range late in the dry season (May) and late in the monsoon season (September-October) since 1995 as part of JORNEX (the JORNada EXperiment). This project is funded by the USDA-ARS in Beltsville MD with ground support from the LTER. The approach is to collect multilevel, multisensor data over several of the main ecosystem types including black grama grasslands, creosote bush shrublands, and mesquite dunes plus a transition zone between grass and mesquite (Rango et al. 1998). In addition to conventional ground truth measurements, the remote sensing measurements collected range from very high-resolution hand-held spectroradiometer data to 1-km resolution NOAA-AVHRR satellite data. Additional measurements are made with a variety of instruments at intermediate elevations.

Aircraft observations are extremely important because they generally provide excellent resolution, cover reasonably large areas, and are flexible in that they can be flown at varying times and with different sensors depending on application. The aircraft observations are also key to the scaling issue, in that detailed field studies can be scaled up to the aircraft data resolution whereas satellite data (Landsat and NOAA/AVHRR) can be scaled down to the aircraft resolution. The variety of resolutions and spectral ranges covered provide an excellent opportunity to decide upon the optimum remote sensing package for different research requirements. Some investigators have called for the very highest resolution possible, whereas others have suggested that it is better to acquire samples which are larger than the intrinsic length scale (e.g., Ni and Li in press), otherwise observations are more likely to represent outliers. JORNEX is committed to making long-term measurements relevant to studies conducted at patch, landscape unit, and basin scales as well as acquiring data for regional scale issues. Similar data are obtained for black grama grasslands and creosotebush shrublands at the Sevilleta LTER; these are important for our cross-site comparisons.

Instrumented watersheds. Two small instrumented catchments were established in 1995 within the creosotebush shrubland, each equipped with three flumes and crest-stage recorders. All flow events through these flumes have been recorded since that time. In addition, one flume in each catchment was recently equipped with a level-indicating transmitter and suspended sediment sampler. Samples collected in this way are also being used for analysis of detailed rillflow hydrographs and nutrient content in runoff water. These instrumented catchments provide data with which to test modeling of rainfall-runoff relationships.

Stressor experiments. Plant communities experience environmental factors in combination, not singly, and thus we are interested in the interactions of livestock grazing, presence of shrubs, drought, and other potential 'stressors' of perennial grassland. In 1994-96, two sites with 18 0.5-ha exclosures each were established within black grama grassland/mesquite ecotones as part of LTER III in collaboration with the USDA-ARS. In 9 exclosures within each site, all individual mesquite plants were severed at ground level and hand removed; this treatment is annually maintained. Twelve exclosures within each site are defoliated acutely in a single 24-hr period by grazing cattle (6 in summer, 6 in winter) to create an annual severe disturbance. The remaining 6 exclosures within each site are undisturbed controls. This experiment was designed to identify various responses to acute disturbance, and influences of vegetation structure in the resistance and resilience of these savannas. Plant species composition and cover, small mammal densities, and soil carbon and nitrogen estimates at this 0.5-ha spatial scale allow us to characterize different community responses as we artificially force vegetation change. We expect these data will be particularly important in identifying key factors that influence vegetation dynamics of grassland/shrubland ecotones, and will be useful in extrapolating data collected at the NPP sites to other parts of the Jornada.

Gravelly Ridges Experiment. Sixteen 0.05-ha plots were established by the ARS in 1938 on a bajada slope dominated by creosotebush. This experiment was established to examine the role of native herbivores and shrub dominance on the vegetation dynamics of degraded desert grassland. Original treatments applied to these plots included 8 plots where all shrubs were severed at ground level and hand removed, and 8 plots that were fenced to exclude lagomorphs. The shrub removal treatment was reapplied to these same 8 plots in 1947, 1956, 1960, 1967, 1989, and 1995. The lagomorph exclusion treatment has maintained its integrity since its inception. Basal cover of perennial grasses and canopy cover of shrubs and suffrutescents have been measured immediately prior to each re-application of the shrub removal treatment. This small but elegant long-term experiment has illustrated the overwhelming effect of dominance by a single shrub species in this environment (Gibbens et al. 1993; Havstad et al. 1999). We have observed the persistence of secondary effects of creosotebush even after its physical removal. We do not understand the full range of processes related to the continued persistence of degraded vegetation states even when common disturbance effects (other than periodic drought) are minimized. The very slow recovery by black grama even on plots where shrubs are removed illustrates the importance of landscape context and soil development in understanding vegetation patterns. This study is located within a large expanse of creosotebush-dominated shrublands, with very few black grama plants occurring in the vicinity. We suspect that seed availability from the surrounding landscape and soil degradation are the major constraints on black grama recovery. We plan to investigate seed availability constraints for black grama in the next phase of our work.

JER permanent quadrats. Between 1915 and 1932, 104 1-m^2 quadrats were systematically located by the ARS in the major grassland types within the Jornada Experimental Range. Quadrats were selectively placed, usually at 0.8 km intervals along lines radiating out from permanent watering points. Placements were subjectively chosen to represent average species composition within the immediate area. Basal area of grasses, canopy cover of shrubs, and species and number of forbs were recorded continuously until 1947 and intermittently to the present. These records have provided, at a very small spatial scale, quantitative data on the striking vegetation changes so typical of the Jornada basin (Buffington and Herbel 1965). Our recent work in digitizing these quadrat data increases their accessibility and utility beyond a simple record of vegetation change. Because these quadrats are located throughout the Jornada, these data are also useful in the extrapolation of data collected at the NPP sites to the basin.

Plant diversity experiment. A major component of human influence (deliberate and otherwise) on semiarid ecosystems is the alteration of plant diversity by species introductions and by species deletions or removals (Huenneke in press). Meanwhile we do not understand completely the degree to which various functional groups of species overlap in resource use or differ in their response to environmental variability (Huenneke and Noble 1996). Biotic change may thus have substantial effects on system productivity and stability. Plant functional group and species diversity has been manipulated within 25 m x 25 m plots of creosote bush shrubland since 1995 by the selective removal of species or species groups. Some treatments involve the removal of all individuals of a functional group (perennial grasses, shrubs, subshrubs, or succulents). Other treatments include removal of the single most abundant species in each of those 4 functional groups, leaving all subordinate species (reduced treatment); and removal of all subordinate species, leaving only one perennial grass species, one shrub species, one subshrub, and one succulent (simplified). Each treatment is replicated 6 times. The experiment affords an opportunity to observe the relationship between plant diversity and various biotic and abiotic aspects of ecosystem function within one landscape unit that will be relevant to the NPP sites located in creosotebush shrublands. Long-term data on plant composition and abundance are acquired from permanent transects within each plot; we have also monitored an index of soil erosion (sediment accumulation in pans at the downslope edge of each plot) and various indicators of vertebrate and invertebrate activity in each plot (Zeisset 1998).

Fire study. In 1998, we initiated a study funded by the BLM to evaluate the role of fire and its interactions with grazing in generating patterns in vegetation across multiple spatial scales. We are also evaluating the effects of fire and herbivory on grasshopper, rodent, bird, and lizard populations. Four 200 m x 200 m plots were located within 4 blocks in a ~400 ha pasture co-dominated by black grama and honey mesquite. Each of four treatment combinations of fire and grazing was assigned randomly to one of four plots within each block: burned and grazed, burned and ungrazed, unburned and grazed, and unburned and ungrazed. Rabbit exclosures within each plot are being used to evaluate effects of herbivory by small mammals on vegetation response. Vegetation data are collected annually at several spatial scales. At the community level, baseline measurements of species basal and aerial cover as well as species composition were collected prior to burning. At population and individual plant levels, we are focusing on black grama and honey mesquite. Densities of grasshoppers, rodents, birds, and lizards were also determined. We are also following the response of a prominent invasive plant species of desert grasslands, Lehmann lovegrass. Fire treatments were applied in June 1999 by burning the entire pasture, except for unburned controls. All measurements will be repeated annually or semi-annually to determine long-term post-fire responses. In addition to adding to our knowledge about the role of fire in desert grasslands (e.g. Cornelius 1988), this experiment will be useful in developing approaches to integrate vegetation data across spatial scales.

Weather and climatological data. Long term daily and hourly climatological data are available online from the Jornada LTER Weather Station, which dates to 1983 and conforms to Level 2 of the Standardized Meteorological Measurements for Long Term Ecological Research Sites document edited by David Greenland. Additional monthly precipitation data are provided from a network of rain gauges established in 1989 at each NPP site. Daily precipitation and temperature measurements are also available from USDA-ARS Jornada Experimental Range Headquarters, beginning in 1914. A large network of precipitation gauges provides information on spatial variation in precipitation inputs across the JER and the CDRRC.

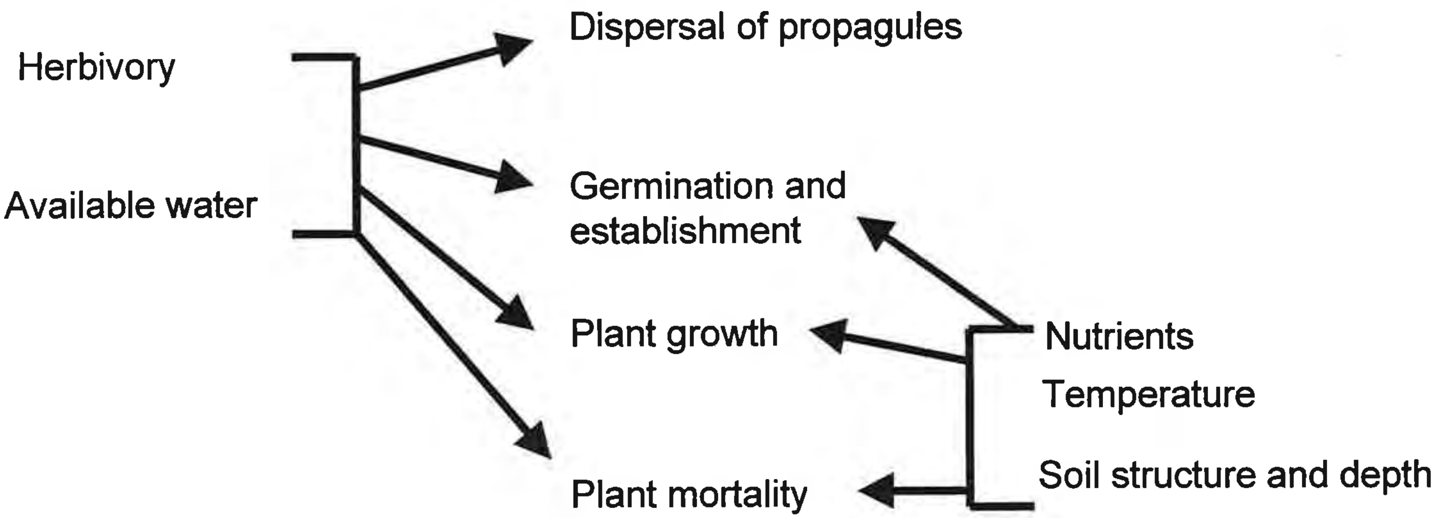


Fig. 2.5 Within landscape unit controls on community structure and dynamics.

Deposition studies. An Aerochem Metrics Wet/Dry Precipitation sampling collector is maintained at the central weather station near Mt. Summerford, and the dataset of atmospheric deposition from individual rainstorms and from monthly collections of dryfall extends back to 1983. Although the NADP has abandoned its use of this type of collector as an accurate measure of dry deposition, we propose to maintain our sampling as a long-term index of dustfall and dustiness in the basin. Data from these collectors have been used to estimate the input of nitrogen to the Jornada Basin, to balance against gaseous losses of NH_3, NO, N_2O, and NO_2 in nutrient budgets for the Jornada Basin (Hartley and Schlesinger in review).

B. Mechanistic and process-level studies and models

As detailed in the Results from Prior Support section, we have made great strides in understanding the mechanisms and the consequences of resource redistribution at the plant-interspace scale within several ecosystem types of the Jornada Basin. The Jornada LTER program has also done much to describe the structure and dynamics of those ecosystems. However, there remains significant unexplained variation (e.g., among creosote bush sites), some of which is likely influenced by the location of a site in the landscape – e.g., whether it receives overland flow from neighboring sites. Also, given the substantial movement of water and other resources within landscape units, there is potential for export or loss of those resources from these units. Thus, integration of fluxes at the landscape or basin-wide scale is necessary to determine whether our semi-arid landscape is a net source (or sink) of those materials, and to determine the contribution of these systems to global carbon and nitrogen dynamics.

Based upon our previous research and ongoing studies, the shorter-term, process-level studies described below are critical to filling in gaps in our knowledge. Although we maintain our interest in smaller (plant-interspace, patch) and larger scales (basin, region), our mechanistic studies will focus on controls on ecosystem processes within and among landscape units represented by the NPP sites. These studies will assist us in understanding smaller-scale patterns where we have observed unexplained variation as well as understanding and predicting larger-scale patterns. Thus, we are focusing our efforts on studies that will address the following three questions relevant to understanding patterns and processes at the landscape scale:

What are the controls on community structure and composition within a landscape unit?

We hypothesize that the major controls on community structure and dynamics are herbivory, available water, nutrients, temperature, wind, and soil structure and depth (Fig. 2.5). These controls operate at several stages in the life cycle of individual plants, from the production and dispersal of propagules to the germination and establishment of seedlings, and growth and mortality of individuals. Much relevant work is already being conducted as part of our long-term studies at the NPP sites. We will add studies to explore constraints on plant recruitment for key species, as well as interactions and feedbacks among these controlling factors -- in particular, vegetation-soil feedbacks.

What are the controls on ecosystem processes and fluxes, both within and among landscape units?

We hypothesize that weather, topography, current plant and animal community structure, soil characteristics, disturbance regimes, and landscape position provide the major controls on movements within and among landscape units. We wish to understand the dynamics of water, nutrients, and populations in our various landscape units, and to determine the degree to which materials and organisms move among units (Fig. 2.2).

What is the relative importance of processes occurring within landscape units compared to transfers of materials or organisms among units, in determining ecosystem structure and function?

We hypothesize that some landscape units are net sources of materials and other landscape units are net sinks. The conditions under which each unit acts as a source or sink vary according to the material considered. For example, mesquite dunelands may be net sources of soil particles due to high erodibility of the surface, yet net sinks of water as a result of high infiltration capacity. By contrast, black grama grasslands are expected to be sources of grass seeds, yet sinks of water and soil particles. The relative importance of processes occurring within a landscape unit compared to between-unit processes is expected to depend upon the type of landscape unit as well as its location within the landscape. Grasslands occurring within a shrub-dominated landscape may be more affected by between-landscape unit fluxes than are grasslands within a large grass-dominated area with less-frequent flows between units.

We first describe new efforts designed to evaluate each of the important controls on ecosystem processes, both within and among landscape units (1). We then discuss new studies aimed at plant population processes and community dynamics that have not been sufficiently studied, yet are expected to be critical to our understanding of these systems (2). Finally, we present our approach to synthesizing and integrating the information in order to evaluate the relative importance of controls, both singly and in combination, in explaining ecosystem dynamics within and among landscape units (3). We emphasize that all of these approaches are integrative, collaborative efforts by listing the multiple investigators who will be most closely involved with each effort.

(1) Major controls on ecosystem dynamics within and among landscape units

Sediment and nutrients can be redistributed by both wind and water, while seeds can be transported by wind, water and animals. An understanding of sediment transport is necessary to understand how current geomorphic patterns developed. These patterns serve as the context within which shorter-term nutrient and water fluxes control plant production. Measuring sediment, water fluxes, and both aeolian and fluvial nutrient fluxes aids us in understanding the relative importance of soil-vegetation feedbacks across multiple spatial and temporal scales.

We plan to analyze current soil and vegetation patterns, together with historic and paleo-historic differences in the evolution of soils and vegetation in different landscape units. This will allow us to stratify the landscape based on its susceptibility to change and to identify those areas which have been the most dynamic. We will then apply our growing understanding of contemporary fluxes to: (a) explain why some parts of the landscape have been more dynamic than others, and (b) develop mass balance models of water and nutrients at time scales relevant to plant growth and vegetation change. We plan to focus hypothesis testing and model validation on the NPP sites.

Geomorphology and soils (Monger, Herrick, Schlesinger). Constraints produced by geomorphology and soils exert major controls on ecosystem structure and dynamics in the Chihuahuan Desert (Monger 1999). Geomorphic constraints include parent material, elevation, and slope aspect, slope length, and slope steepness (which, in turn, control the location of runoff and run-on areas). Soil constraints include the capacity to capture, retain, and supply water, supply nutrients through mineral weathering and organic matter mineralization, resist erosion, and provide a favorable environment for root growth and soil faunal activity (a function of shrink-swell properties and other factors). The first objective of our geomorphology and soils program is to quantify the relationship between ecosystems and geomorphic/soil constraints using GIS. We propose to overlay a series of vegetation maps dating back to 1858 on maps of erosional areas, depositional areas, parent materials, landforms, soil types, and chemical maps of the Jornada Basin (Fig. 1.8). Knowledge to be gained from these studies will be: (1) the identification of landscape units where ecosystems have been most dynamic or stable, and (2) the identification of landscape units that are sources or sinks of biogeochemical resources.

Soil horizons rich in calcium carbonate represent an important but poorly understand component of many arid landscapes. Soil carbonate is a fundamental constituent of most desert soils. It stores atmospheric carbon (Monger et al. 1991), alters soil water movement and storage (Cunningham and Burke 1973) and is an indicator of soil age (Cole and Monger 1994). Although soil carbonates have been studied in their natural setting in deserts throughout the world, field experiments that accelerate the rate of carbonate formation and measure the resulting impact on water holding capacity are lacking. This information is critical to our understanding of the effects of carbonates on plant available water. Using water with elevated concentrations of Ca^{2+} from added $CaCl_2$, we will irrigate desert soils to a depth of 1 m repeatedly upon drying. The experiment will be set up in both creosotebush shrubland and black grama grassland. The soils in both ecosystem units are Holocene Entisols that are only slightly calcareous. These sites will be monitored four times each year for (1) rate of carbonate formation, (2) depth of carbonate formation, (3) effect of carbonate on soil moisture retention characteristics, (4) involvement of roots and microorganisms on carbonate precipitation as determined with microscopy, and (5) $\delta^{13}C$ of carbonate.

Finally, soils at each NPP site will be thoroughly described in terms of their relative capacity to supply water and nutrients to plants at different depths. Soil samples will be removed from each horizon from locations paired with each of the existing neutron probe tubes, allowing the samples to be used for neutron probe calibration. Soil texture, bulk density, water holding capacity, nutrient availability, organic matter content, carbonate content and stage of calcic horizon development, and root density will be determined for each horizon. Soils will be composited by site for some analyses.

Wind and nutrients (Gillette, Schlesinger). We have demonstrated that wind is important in redistributing materials across landscapes at the Jornada, and that mesquite sites are the most significant generators of dust. Redistributions and losses of soil nutrients by aeolian processes are likely to dominate the soil nutrient budget for N. We will expand our program of process-level studies to examine basin-scale nutrient redistribution by wind and water during LTER IV. We propose to move to basin-wide, source-sink studies of dust and sand emissions by expanding our monitoring to the NPP sites. Three-month BSNE [Big Spring Number Eight] collections of airborne sand and finer particulate material will be used to calculate horizontal mass fluxes at each NPP site. Because of the importance of mesquite sites to dust generation, our primary objective in the first two years is to establish why mesquite dunelands are prolific areas of dust emission. We propose later to investigate specifically what nutrients are being transported to and from mesquite sites and what nutrients are being lost from the source areas of dust emission. Plant coverage, geometry of plant patterns on the landscape, and other aerodynamic features and soil factors that can influence dust redistribution will be examined.

At the three NPP sites dominated by mesquite, grids of particle samplers and micro-meteorological masts will be used to probe the aerodynamic mechanisms for particle emission. Additionally, Sensit™ sand motion sensors will be continuously monitored for the onset and intensity of erosion at each mesquite NPP site. For the first two years of the mesquite site measurements, special attention will be paid to the fine material captured by the 1-m high BSNE particle collections. That work will provide calibrations to relate airborne fine particulate material at the NPP sites to the particulate material captured by the BSNE samplers. Following this calibration work, we propose to analyze the BSNE material for chemistry. We will also place Reheis atmospheric deposition collectors at each NPP site near the BSNE collectors. These samples will be weighed for quantity of deposition and will also be chemically analyzed to compare with the BSNE collected airborne erosion material. A synthesis of the experimentation will be the construction of a model for dust emissions for the Jornada basin. Ultimately, these studies will allow us to estimate losses of N and P from each landscape unit and the redistribution/deposition of these materials in adjacent landscape units within the basin. Using maps of vegetation distribution in the 1800s, late 1920s, and today, we can estimate the changing source/sink relations of various landscape units of the Jornada Basin, and the net aeolian transport from the basin that may have accompanied past vegetation changes.

Water and nutrients (Abrahams, Parsons, Wainwright, Schlesinger). The horizontal transport of stormwater runoff across a desert landscape and its ultimate disposition -- either as a contribution to soil water storage or to immediate evaporation to the atmosphere -- is crucial to determining the availability of water for plant growth. When the hydrologic connections are disrupted, desert vegetation declines (Schlesinger and Jones 1984).

Investigations of surface hydrology have so far focused on studies of nutrient fluxes in runoff within the creosote and grassland bajada (Schlesinger et al. 1999). We plan to extend these studies in three ways. First, we will look at similar fluxes in other landscape units, in particular in the mesquite dune and tarbush areas. These experiments will be undertaken using rainfall simulation on small plots to provide data comparable to those obtained in LTER-III. Small-scale experiments on hydrologic and sediment fluxes that have been undertaken on the creosotebush and grassland bajada will be extended to other vegetation communities, particularly the mesquite dunes. In addition, we will extend the scope of our existing instrumented watersheds to measure bedload sediment transport as well as suspended-load transport.

In addition to water, soil nutrients are also redistributed by hydrologic and aeolian processes. Schlesinger et al. (1999, in press) documented an increased loss of nitrogen from desert hillslopes as grass cover declines and shrubs invade. Thus, a second focus of work will be to examine nutrient movement within and between landscape units by studying nutrient transport in rills and other areas of concentrated water flow. Existing sampling equipment within a rill network on the creosotebush bajada will be used to study water, sediment, and nutrient movement within this community. We aim to install further instrumentation on rills, and possibly a sandy wash, that transgress from one vegetation community to another. In addition, we intend to set up a network of samplers to measure nutrient content in runoff water. Approximately 100 of these samplers will be located in a variety of topographic and ecological settings across the bajada. The collections from episodic runoff events will be analyzed for nutrient and tracer elements important to desert soils. These studies will allow us to predict the long-term horizontal transport of N from upslope positions that are often dominated by residual grasslands to downslope shrubland habitats and seasonal playas. In addition, we will continue the collection and nutrient analysis of waters from two instrumented watersheds in the creosotebush shrubland. These data will allow us to reformulate and rescale nutrient budgets that currently exist for individual habitats to landscape-level nutrient budgets. Third, we will perform experiments to examine the effects of nutrient transport into tarbush areas by depriving selected tarbush sites of water and nutrient influx (surface flow diversion). Results will be compared against two control sites, one with natural water inflow replaced by nutrient deficient inflow, the other left under natural conditions.

Another major component of the study of hydrologic, sediment and nutrient fluxes will be the development of a numerical model. One of the significant problems for modeling in low relief areas, such as the majority of the Jornada Basin, is an adequate characterization of the topography. Our preliminary study using digital photogrammetry on the creosotebush landscape demonstrated that this technique is viable for producing an accurate and detailed DEM of the ground surface, which is necessary for process-based modeling of water, sediment and nutrient transfers. However, the 1996 photography has poor ground control and is at a relatively coarse spatial scale. We therefore propose to obtain new aerial photography in collaboration with the remote sensing project (see below), with better ground control and higher spatial resolution, from which we will produce a series of DEMs for key sites within and across vegetation-community boundaries. Because it will not be possible to produce a DEM at this scale for the whole basin, we will compare the characteristics of these DEMs with the coarser scale DEMs which are already available for the basin. In this way, it will be possible to extrapolate these characteristics across the whole basin.

In order to apply process-based models at the basin scale, it is necessary to develop methods to obtain appropriately-scaled model parameters from other than very local field measurements. We will use remotely sensed data obtained both from satellite-based instruments and our proposed overflight to estimate these parameters. By obtaining data at different scales (field measurements, overflight imagery, satellite imagery) we will be able to develop techniques for the scaling of measurements.

Our existing bajada-scale model (Howes 1999) will be further developed and applied using data obtained both from LTER-III and from new experiments to be undertaken in LTER-IV. Validation of the model can be carried out using existing data from previous LTER work (e.g. neutron-probe measurements along the transect from Summerford Mountain to College Playa). However, we also envisage a limited program of field experiments to test specific model predictions (e.g., the isolation of a tarbush site from water, sediment and nutrient transfers from upslope, as described above). It may also be possible to instrument existing stock ponds to provide data on larger scale transfers. Once validated, we will conduct scenarios with the model, for example over the longer term, using the existing climate and vegetation-survey data, or looking at the impacts of potential future climate change. We will also link the hydrology model with our vegetation model (ECOTONE) to simulate dynamic interactions and feedbacks between vegetation, water, and nutrients.

We will use our hydrologic model, together with DEMs, weather data and PET estimates for each community (see ecophysiological work proposed below), to develop a monthly water balance for each NPP site. The water balance estimates will be calibrated using historic data and validated using current data. (A similar process could be undertaken for nutrients, incorporating atmospheric deposition, biological fixation and redistribution by wind and water. However, the lack of historical nutrient data for the NPP plots and even more limited database on plant-availability limits our ability to make inferences at the same level as we can for water.)

Remote sensing component (Rango and all others). We propose to move beyond the remotely-sensed data being collected through the JORNEX project (see Long-term studies, above) to direct support of the other process-level studies described here. In particular, the remote sensing measurements being developed will be used to provide data on hydrologic and nutrient fluxes. We will provide data on shrub or patch location, patterns of shrubs or patches over the landscape, rill or drainage patterns, and digital elevation models (DEM). These data will be useful for measuring parameters for physically based models operating at the LTER study sites in the various ecosystems. LIDAR data provide the best DEM capabilities and can be registered with other data such as multispectral video to increase resulting information content. Unfortunately, LIDAR data are very expensive to obtain. Where LIDAR data already exist at Jornada, we will rely upon them heavily. Where they do not, we will acquire high-resolution aerial photography with good ground control to develop DEMs over the specific LTER study sites. At the same time, we will continue to explore ways to increase LIDAR coverage.

The remote sensing data will be used to assess differences and similarities between the NPP sites. The remote sensing approach will be useful in extending information from these intensive study sites as well as others to areas in the Jornada Basin where intensive studies are not possible. At the same time, because the same remote sensing methodology can be used in many areas, cross-site comparisons between similar LTERs (e.g., Sevilleta, Shortgrass Steppe, and CAP) become a real possibility. The remote sensing data can be used to develop patch- to landscape-scale comparisons as well as for input to physical process and mesoscale models at each LTER. The common approach will facilitate cross-site and regional comparisons where remote sensing approaches are necessary to effectively carry out such large-scale studies.

Herbivory and livestock impacts (Lightfoot, Havstad). Herbivory by arthropods and cattle is another process that can affect ecosystem processes through seed and seedling mortality, reduction in plant reproductive potential, and alteration of rates of nutrient cycling and plant litter production (Holechek et al. 1989; Brown and Heske 1990; Kerley and Whitford 1994). Although these effects are most important within landscape units, reductions in seed production would also affect the ability of plants to disperse among units. Because we know so little about small herbivore impacts on plant processes, our initial focus will be within landscape units. Thus far, our studies of arthropods have been restricted to ground-dwelling groups, chiefly detritivores and predators. We will expand our studies to include phytophagous plant-dwelling insects and grasshoppers: two groups that can have high rates of herbivory in desert ecosystems. We will monitor species composition and abundance of these groups at each NPP site using visual observations and sweep nets. Selective herbivory by all groups will also be studied using exclosures of different sizes placed on plants of important species. Removal of foliage and reproductive plant parts will be measured over time and compared to control plants to determine effects on flower and seed production. Effects of herbivores on plant seedling mortality will also be studied using small exclosures to protect seedlings of important plant species from herbivores. Diets and consumption rates of rabbits, rodents, and insects will also be studied at each NPP site. Fecal analyses and quantitative field observations will be used to determine the quantities of plant material selected by different herbivore groups. We will develop foraging time budgets using field observations. Laboratory studies will be used to determine consumption rates of insects on different plant species.

As part of a continuing effort to understand the role of livestock in Chihuahuan desert ecosystems, we will also investigate the importance of altered patterns of large animal movements over the history of livestock management in the basin. There exists an 85 year legacy of studies on the effects of livestock grazing on the ecosystems of the Jornada (Buffington and Herbel 1965). However, an important gap in our understanding of livestock impacts on desert environments is our lack of knowledge of grazing impacts at the landscape scale: livestock as agents of flux between landscape units. We know that grazing can create heterogeneity, and we know that grazing is in turn strongly influenced by heterogeneity. Current principles used in grazing management do not consider the interacting roles of heterogeneity within and among landscape units. Obviously, the effects of grazing will differ depending upon the scale examined. In order to understand grazing effects within and among units we need to know when and where grazing occurs across a continuum of spatial and temporal scales. As an initial step, we will characterize grazing dynamics across landscape units. There are several large areas (>4,000 ha) in the Jornada basin without internal fences, that each contain the 5 different NPP ecosystem types, and that are well-described in terms of vegetative, topographic, and edaphic features. We propose to equip free-ranging cattle with high-precision GPS tracking equipment that will allow us to characterize the timing and location of grazing. We plan to periodically estimate diets and intake to characterize within-unit herbivore and among-unit propagule distribution. We propose to use two very different types of cattle to understand the range of possible grazing behaviors across this landscape. We will use the typical cattle for this environment, the English breeds that contain a small percentage of *Bos indicus* genetics, and we plan to use the more historic Spanish breeds of cattle (Corriente) first used in this region 400 years ago and still present in Mexico. These studies, combined with related work (e.g., on plant phenology), will allow us to describe grazing dynamics across landscape units. Finally, we will exploit our extensive records of the history of management over the past 85 years to compare areas of long-term heavy impacts (e.g., near the oldest watering points in the JER) with more recently or more lightly used areas on comparable landscape units. These comparisons should illustrate the potential magnitude of introduced grazers as modifiers of ecosystem structure.

Animals as agents of soil disturbance (Lightfoot, Herrick). Disturbance increases the susceptibility of soil to erosion by wind (Belnap and Gillette 1998) and water (Herrick et al. 1999; Neave 1999). Animals can also have large effects on soil surface particles through digging and tracking across the surface. Few studies have been conducted to determine how much of the soil surface is disturbed by animals in arid environments, and even fewer studies have assessed the significance of animal-induced soil surface disturbance to soil erosion. Information on the frequency and extent of animal disturbance, and on the relationships with soil erodibility and erosion, will contribute to our understanding of wind and water erosion processes and the pattern of soil redistribution across the landscape. Undisturbed soil surface particles typically adhere together through a combination of inorganic and organic interactions. Related studies on the role of vehicular and livestock trampling disturbances on the Jornada suggest that cryptogams appear to play a particularly important role in soil aggregation. Disturbance type and amount, and dry and wet aggregate stability, will be monitored every 4 months for one year in all Small Mammal Exclosure Study plots (see Long-term Experiments and Core Datasets, above) and in paired fenced and unfenced plots (5 m x 5 m) at each NPP site. Based on the results of these measurements, we will design additional studies to more effectively quantify the effects of different types, frequencies, and intensities of disturbance using rainfall simulation and a portable wind tunnel. These experiments will allow us to quantify the effects of small animals on soil surface stability and redistribution.

(2) Plant population and community dynamics

A number of gaps in knowledge remain relative to the potential response of vegetation to environmental controls across multiple spatial scales. In particular, we will focus on recruitment and mortality processes of dominant species (black grama, creosotebush, mesquite) in Chihuahuan desert ecosystems. Controls on these processes are poorly understood, yet likely explain much of the observed within and between landscape unit variation. Competition for limiting resources, in particular water and nitrogen, between these species has been studied previously in the context of our plant-interspace work. Although our understanding of competition is still incomplete, the lack of information on recruitment and mortality led us to shift our focus to these processes. These studies along with new ecophysiological studies will complement our long-term monitoring of plant populations and communities. These data will also be important in parameterizing and validating our model of vegetation dynamics (ECOTONE).

Plant populations (Peters, Huenneke). We propose to initiate long-term studies of recruitment of black grama, creosotebush, and mesquite at the NPP sites, to complement work done elsewhere in the basin (e.g., Miller and Huenneke in press). We will evaluate seed production of each species by harvesting seeds and other reproductive structures for individual plants of each species adjacent to each NPP site. Seed viability will be determined using standard methods for each species. Soil samples will be collected prior to seed maturation and dispersal, and again the following spring prior to germination and establishment. Number of seeds (germinable and total) of all species will be determined using greenhouse germination studies followed by manual extraction of the remaining seeds from the samples. These analyses will provide a measure of seed availability for germination and establishment for all species, and a measure of recruitment potential based on production of viable seeds for dominant species (Peters submitted). Comparisons through time of soil seed bank composition with the plant community at each NPP site will indicate the degree of dispersal of seeds into the sites from neighboring landscape units. Constraints on germination and establishment of seedlings will be evaluated for the dominant species using field and greenhouse trials combined with simulation modeling (Peters in press). The long-term datasets from individual quadrats of the NPP study should provide estimates of observed recruitment rates to compare with these investigations. Similar studies will be conducted at the Sevilleta LTER for black grama and creosotebush, allowing us to evaluate geographic variation in recruitment potential of these species.

We propose to analyze existing datasets (JER permanent quadrats and NPP sites) and initiate new studies to determine the turnover rate of individual plants of our key species within each landscape unit. Although studies have been conducted to estimate longevity of plants of black grama, creosotebush, and mesquite (Wright 1972), little is known about the turnover rates of plants and the causes of mortality. Also, the length of time required for standing dead plants to decompose sufficiently to create patches for successional dynamics to occur is unknown, though this likely varies between grasses and shrubs. These patches provide opportunities for the establishment of seeds that disperse either from within a landscape unit or between units. We will use low-level aerial photos combined with field surveys to identify and label individual plants of each species to be monitored through time for various measures, including height, volume, and biomass estimated from the NPP regressions. Standing dead plants will also be identified and followed through time. The relative importance of small scale vs. large scale and acute vs. chronic disturbances will be assessed by examining the spatial distribution of mortality over time. We have proposed studies (for separate funding by NSF International Programs) that will document the size and frequency of occurrence of small-scale disturbances for the Jornada as well as the Sevilleta and Shortgrass Steppe LTER sites and three intermediate sites along a north-south climatic gradient.

Ecophysiological analysis of NPP patterns (Gutschick, Huenneke). The striking interannual variability of NPP (Fig. 1.4) demonstrates a far more complex relationship between NPP and precipitation than suggested by the linear relationship described by Lauenroth and Sala (1992). Our results suggest that the relationship between NPP and precipitation must take into account both spatial and temporal variation in both factors, and potentially other factors as well. We will use an ecophysiological approach to provide a better understanding of the controls on NPP with a focus on water in these dry systems.

We expect that NPP (by species, site and season) is related to daily evapotranspiration multiplied by water-use efficiency (WUE). WUE is currently calculated as a function of the micrometeorological and leaf stomatal behavior. Stomatal conductance and WUE are computed using robust formulations of stomatal control (the model of Ball et al. 1987, tested on many species on the Jornada) within a complete model of leaf energy balance, stomatal conductance, and photosynthetic assimilation. Evapotranspiration must be estimated for each site. We will improve the quality of ecophysiologically-based NPP predictions by refining our analyses of NPP and related datasets, including plant phenology.

Community structure by automated image analysis (Gutshick, Rango). In earlier attempts to compare predicted and measured fluxes (heat, water vapor) on 300 m x 1000 m transects, we developed methods for high-quality aerial photography and analysis of digitized photos in order to estimate leaf area index (LAI). A key component of LAI estimation is identification of individual plants to species, because leaf clumping (and photosynthetic capacity) varies with species. In brief, we found that any shrub or patch of grass in a chosen rectangle can be analyzed for 9 to 18 characters (spectral characters such as mean hue and mean saturation, and spatial characters such as mean gap length between branches). These characters can then be used to train neural network algorithms to identify species. Initial attempts, using images from a single time and date, allowed resolution of only 3 species at a time. We are currently testing images from two dates, between which phenologies of major species differ, to resolve 8 - 12 major species.

We propose here to perfect and apply these image analysis methods for two purposes: (1) quantification of LAI, APAR, and roughness for the flux studies described earlier, and (2) analysis of community structure, including neighbor distances, contagion in species distributions, and stratification of plant size by neighbor density. Such community structure studies should aid the work described under "Community dynamics," by bringing the studies to larger spatial scales (up to 1 km), containing very large samples of plants (over 100,000). The persistence of establishment patterns at these larger scales merits testing, which can only be done by automated methods applied to aerial photographs, as proposed here. The exact transects to be analyzed will be chosen in order to test the degree to which community patterns vary across the landscape. Species-recognition algorithms (neural nets, fuzzy neural nets, neural fuzzy nets) are currently being studied with R. Prasad of NMSU, Electrical Engineering, under funding for global-change studies (DOE) and will be developed further.

(3) Synthesis and integration to determine the relative importance of controls within and among landscape units

We will follow a three-step process to synthesize existing data and determine the relative importance of controls within and among landscape units on ecosystem dynamics and biotic patterns: (a) identify key controls using analyses of long-term data, (b) adapt and run ECOTONE linked with our hydrologic model, both with and without resource redistribution among landscape units, (c) use the results of these analyses to generate new testable hypotheses about the relative importance of different processes to dynamics at different spatial scales, and to design experiments to test these hypotheses across a range of scales.

(a) Identify key controls using analysis of long-term data. Much of the synthesis of individual factors is included in the individual components discussed above. We will supplement these analyses by applying multiple regression and other statistical approaches to two key datasets

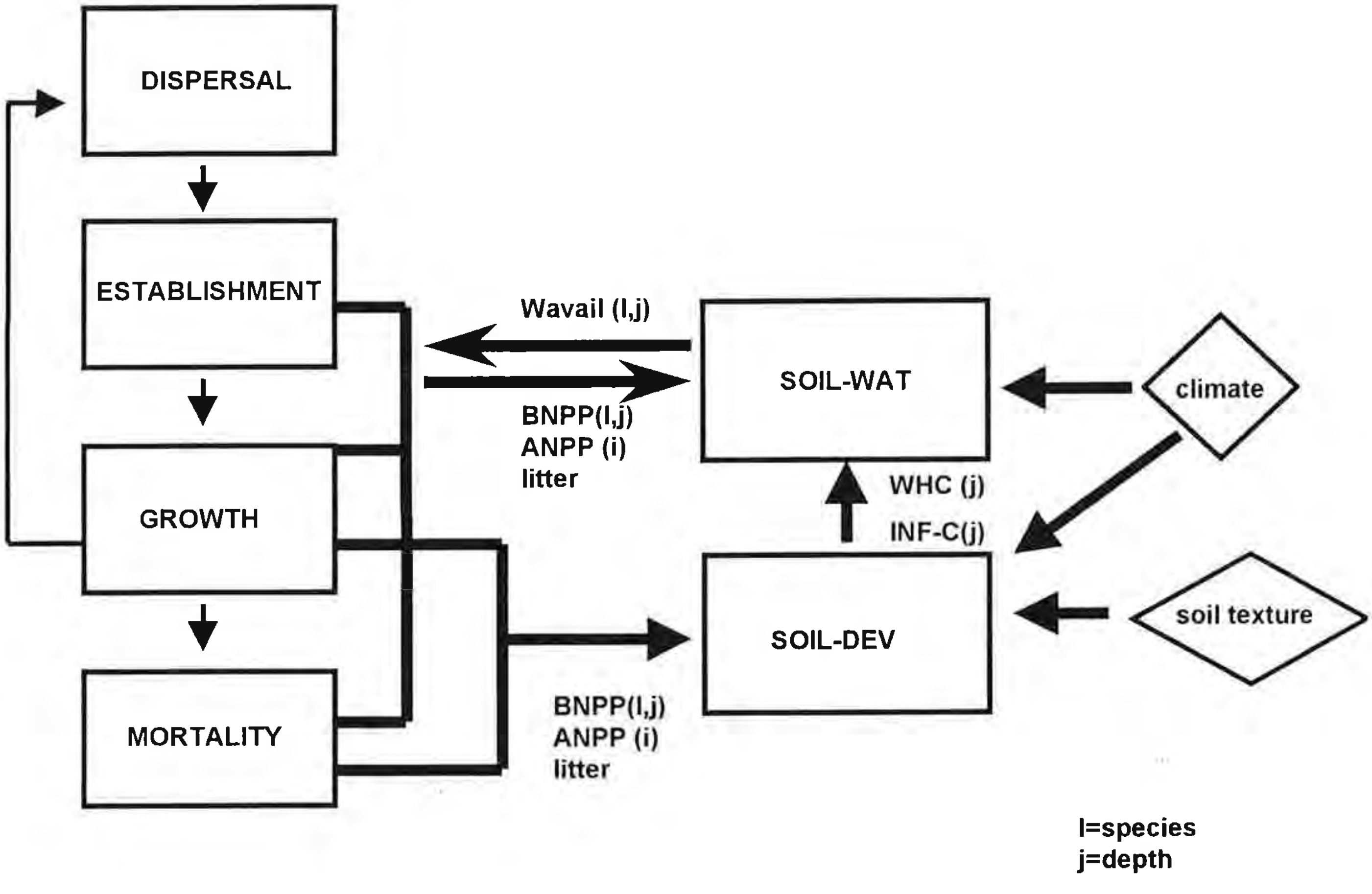


Fig. 2.6 ECOTONE simulation model of vegetation and soil water dynamics. Nutrient dynamics will be incorporated as part of our proposed work.

(NPP and the JER permanent quadrats) together with more specific studies, including the stressor experiments, the Gravelly Ridges experiment, the plant diversity experiment, plant phenology and consumer monitoring, the small mammal exclosure study, the LTER I transects, soil water measurements, and the fire study. We will begin by using multiple regression to attempt to explain the 60+ year vegetation record in the JER permanent quadrats using landscape-level factors: geomorphic surfaces, precipitation patterns, and livestock grazing. A similar approach will be applied to the NPP dataset, incorporating the results of analyses described under "Mechanistic level studies".

(b) Model analyses comparing results with and without redistribution among landscape units. We will use a spatially-explicit vegetation model (ECOTONE) linked with our hydrologic and wind erosion models to evaluate the relative importance of redistribution among landscape units. ECOTONE is an individual plant-based gap dynamics model that simulates recruitment, growth and mortality of each plant on a small plot at an annual time step (Peters and Herrick submitted). Driving variables include climate, soil texture and disturbance. The model simulates dominant species and 8-10 additional groups of species representing various life history traits (shrubs, annuals and short-lived perennial C3 and C4 grasses and forbs). We incorporated a daily time step, multi-layer model of soil water (SOILWAT; Parton 1978) into ECOTONE to allow seasonal soil water dynamics to affect and be affected by the vegetation. Daily soil water information is passed to the establishment and growth routines on a daily or monthly basis. We also added a soil development module (soil-dev) to allow vegetation to affect soil properties with feedbacks to plant growth and establishment (Fig. 2.6) (Peters and Herrick submitted).

Our future modeling plans include adding competition for nitrogen and light into ECOTONE. We recently integrated nutrient cycling routines from the CENTURY model (Parton et al. 1988) into ECOTONE in order to simulate the feedbacks between plant production and C and N pools on a daily or monthly basis. Under separate NSF funding (DBI – 9630264), we have rewritten and restructured ECOTONE in C/C++ as a multi-scale, spatially-interactive model that can represent multiple patch types distributed across a landscape. We plan to simulate interactions among landscape units throughout the Jornada Basin by linking this version of ECOTONE to the hydrologic and wind erosion models described above (Fig. 2.7). This work will be coordinated with a similar modeling effort at the Sevilleta LTER.

The results of the integration analyses above (a), together with data from new experiments, will be used to parameterize ECOTONE and to predict patterns of vegetation change without resource redistribution. We will then incorporate redistribution of water, nutrients and seeds. The results of these two sets of model runs will be compared to determine the relative importance of within- and between-landscape unit interactions, and of transfers of different resources, for different ecosystem types.

(c) Generate testable hypotheses concerning key processes and potential feedbacks. We recognize that in addition to fluxes of materials among landscape units under existing conditions, there are many potential feedbacks occurring at the landscape level. These include shifts in population dynamics and grazing patterns in response to annual differences in NPP in different parts of the landscape which, in turn, may be driven by both the amount and intensity of precipitation. Model runs described under (b) will be used to generate hypotheses concerning key processes and potential feedbacks. Additional analyses and model runs will be used to address some of these potential feedbacks. Model runs will also be used to guide the design of new experiments to test these hypotheses across a range of spatial and temporal scales.

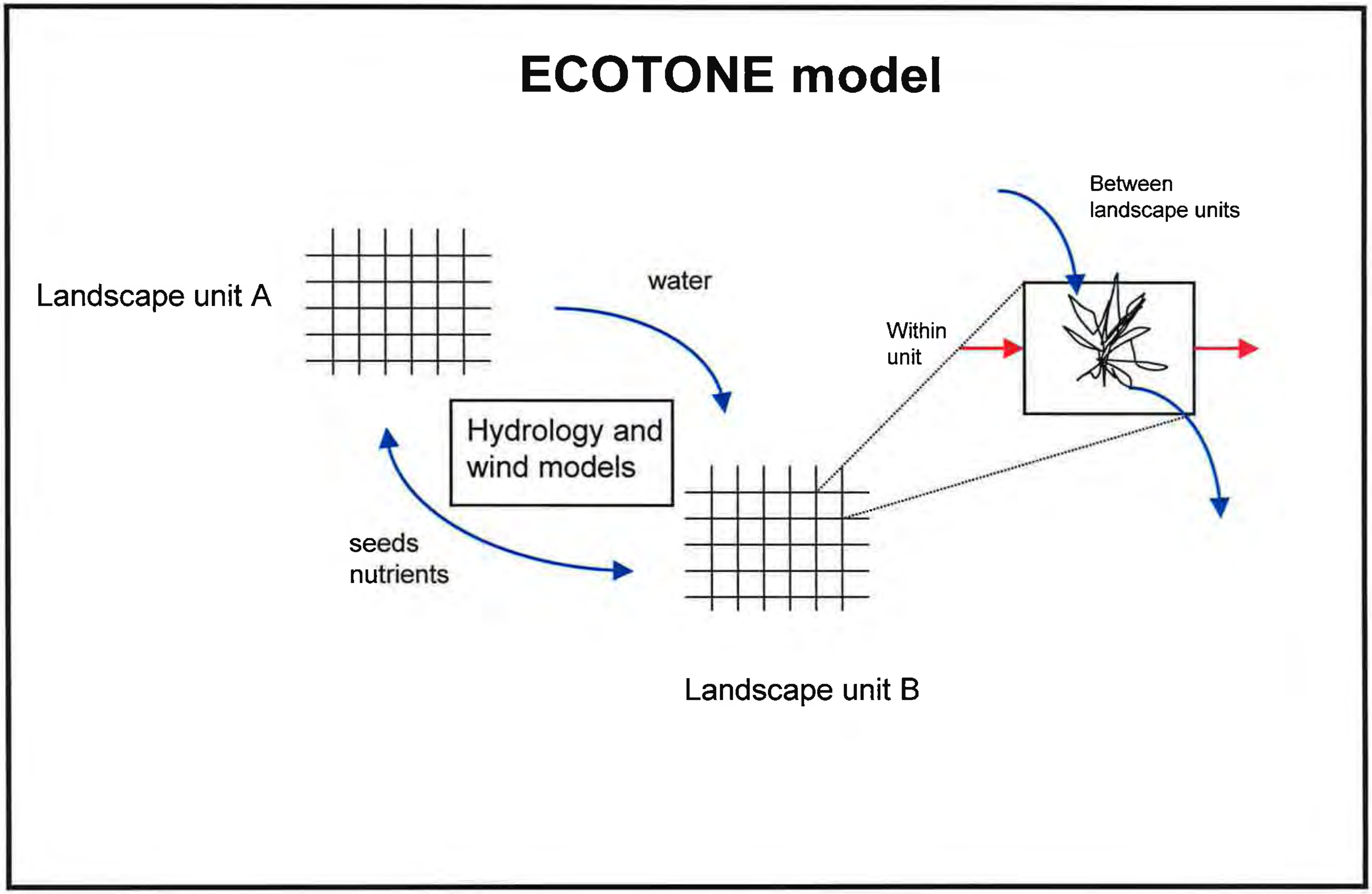


Fig. 2.7 Spatially-interactive ECOTONE model that links the vegetation, hydrology, and wind erosion models to simulate biotic processes and flows of materials both within and among landscape units. The model will simulate vegetation, soil water, and nutrient dynamics on a grid of interactive plots within each landscape unit.

C. Cross-site and regionalization efforts

Semiarid ecosystems are widespread across the globe, and the understanding of ecosystem dynamics and of desertification processes developed by the Jornada LTER program has relevance to many other locations. Our cross-site and regional studies are designed to allow us to test the generality of our hypotheses and results by working under a broader range of environmental conditions and plant communities than currently found at the Jornada. Most of our comparisons focus on a north-south regional gradient that extends from the northern limits of the Chihuahuan desert in New Mexico (Sevilleta National Wildlife Refuge [SEV]-LTER) to the southern Chihuahuan desert in Mexico (Mapimi Biosphere Reserve) (Fig. 2.1e). Big Bend National Park in west Texas and La Campana Experimental Range in the state of Chihuahua provide additional sites within the gradient. These satellite sites for experimentation and monitoring are augmented with remote sensing, simulation modeling, and GIS to extend our results to the entire region.

A number of our vegetation studies, experiments, and simulation model analyses have comparable efforts at the SEV-LTER and SGS-LTER sites. In many cases, we are using similar methods at the three sites to test our hypotheses and allow valid cross-site comparisons. A number of the comparisons are also being made in grasslands in Hungary and Israel. The cross-site studies are listed in Table 2.2 due to space constraints.

V. Overview and summary

The overall objective of the Jornada Basin LTER program has been to understand the causes and the consequences of desertification in semiarid ecosystems. In the past 6 years, we have established the validity of the major components of the resource redistribution model of desertification. We have documented the increased heterogeneity of soil resources in shrublands relative to grasslands, and have explored the physical processes promoting that heterogeneity at the scale of an individual plant and neighboring interspace. We now propose to take the next logical step of examining these redistributions at larger spatial scales, particularly those of relevance to human use of semiarid landscapes. The new work proposed here is aimed explicitly at those larger scales, and is focused on linkages or flows across the landscape and the relative magnitude of within- versus between-landscape unit factors. Specifically, we propose to synthesize and integrate existing datasets in a landscape context, and to investigate landscape fluxes of water, nutrients, and organisms in order to evaluate key processes affecting ecosystem dynamics at this scale. We will organize our research around an existing network of 15 sites in 5 different ecosystem types located throughout the Jornada basin. We will supplement our long-term studies with new mechanistic and process-level studies designed to identify the relative importance of fluxes between and among landscape units. We will use simulation modeling to synthesize and integrate these data in order to elucidate the key processes affecting ecosystem dynamics at different spatial scales. This exercise will lead to new field experiments directed at specific aspects of Chihuahuan desert ecosystems, and will improve our understanding of processes involved with both the desertification and the remediation of these ecosystems. Cross-site and regional studies will be used to test the generality of our hypotheses, and will allow us to apply our results to many semi-arid regions worldwide.

Table 2.2. Summary of major cross-site and regionalization efforts by Jornada LTER investigators.

TITLE	SITES	PI(s)	Collaborators	Funding
Effects of indigenous small mammals on plant community composition and structure	SEV/JRN/Mapimi, Mexico	Lightfoot	L. Hernandez	NSF/LTER
Climate change, topography, & southwestern arthropods	SEV/JRN/Bandelier National Monument/Los Alamos	Lightfoot		NSF/LTER, USGS/BRD, DOE
Effects of grazing and climate change on vegetation and grasshoppers in New Mexico semi-arid grasslands	SEV/Bosque del Apache N.W.R./JRN/Fort Bliss (Army) /White Sands MR	Lightfoot, Huenneke		USGS/BRD
Regional variation in recruitment of blue grama and black grama	SEV/JRN/SGS	Peters		NSF/LTER
Removal of dominant species	SEV/JRN	Peters, Huenneke	J. R. Gosz (SEV)	NSF/LTER
Long-term ANPP monitoring	SEV/JRN	Huenneke, Lightfoot	J. R. Gosz (SEV)	NSF/LTER
Effects of fire, grazing, and small mammals on vegetation, birds, grasshoppers, rodents, and lizards	SEV/JRN	Havstad, Lightfoot, Peters	J. R. Gosz (SEV)	NSF/LTER, BLM, ARS
Patterns in biodiversity across spatial scales; simulated effects of climate change on semiarid grasslands	SEV/JRN/SGS/3 sites in Hungary	Peters	E. Kovacs Lang, Sandor Bartha (HAS); Gosz (SEV)	NSF (INT 9513261)
Vegetation-soil feedbacks and response of grasslands and shrublands to climate change	SEV/JRN	Peters, Herrick		NSF/LTER, ARS
Biosphere-atmosphere interactions and shifts between grasslands and shrublands	SEV/JRN	Peters, Herrick	R. Pielke (SGS-LTER), J. Eastman (CSU)	ARS
JORNEX remote sensing project	SEV/JRN	Havstad, Rango	J. Ritchie (ARS)	ARS, NSF/LTER
Soil surface disturbance impacts on ecosystem function	JRN/Moab/Holloman AFB	Herrick	J. Belnap (USGS/BRD)	DOD, ARS, USDI
Ecological monitoring systems for grasslands, shrublands, and savannas	JRN/La Campana, Mexico	Herrick, Havstad, Huenneke	A. Melgoza and M. Rollo (INIFAP)	ARS, CONACyT, INIFAP
Comparative reproductive ecology of *Opuntia* spp.	JRN/Mapimi, Mexico	Huenneke	M. Mandujano (UNAM)	UNAM, CONACyT, LTER
Microbiotic crusts and arid ecosystems	SEV/JRN/Negev Desert, Israel	Monger, Herrick	T. Jones (NMSU), G. Kidron (Israel)	IALC

LITERATURE CITED

Abrahams, A.D., P. Gao, and F.A. Aebly. In press. Relation of sediment transport capacity to stone cover and size in rain-impacted interrill flow. Earth Surface Processes and Landforms.

Ball, J.T., I.E. Woodrow, and J.E. Berry. 1987. A model predicting stomatal conductance and it's contribution to the control of photosynthesis under different environmental conditions. PP 221-224 in J. Biggins (editor). Progress in Photosynthesis Research, vol. 4. M. Nijhoff, Dordrecht.

Belnap, J. and D.A. Gillette. 1998. Vulnerability of desert soil surfaces to wind erosion: the influences of crust development, soil texture, and disturbance. J. Arid Environments 39: 133-142.

Brown, J.H. and E.J. Heske. 1990. Control of a desert-grassland transition by a keystone rodent guild. Science 250: 1705-1707.

Buffington, L.C. & C.H. Herbel. 1965. Vegetational changes on a semidesert grassland range from 1858 to 1963. Ecological Monographs 35: 139-164.

Cole, D.R. and H.C. Monger. 1994. Influence of atmospheric CO_2 on the decline of C4 plants during the last deglaciation. Nature 368: 533-536.

Cornelius, J.M. 1988. Fire effects on vegetation of a northern Chihuahuan Desert grassland. Ph.D. Dissertation, New Mexico State University.

Cornelius, J.M. and G.L. Cunningham. 1987. Nitrogen enrichment effects on vegetation of a northern Chihuahuan Desert landscape. PP 112-116 in E.F. Aldon, E.F., V. Gonzales, E. Carlos, and W.H. Moir (editors). Strategies for classification and management of native vegetation for food production in arid zones. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Tucson, AZ.

Cunningham, G.L. and J.H. Burke. 1973. The effect of carbonate deposition layers (caliche) on the water status of *Larrea divaricata*. The American Midland Naturalist 90: 474-480.

Gibbens, R.P., K.M. Havstad, D.D. Billheimer, and C.H. Herbel. 1993. Creosotebush vegetation after 50 years of lagomorph exclusion. Oecologia 94:210-217.

Hartley, A.E. and W.H. Schlesinger. In review. Environmental controls on nitrogen fixation in northern Chihuahuan desert soils. Soil Biology and Biochemistry.

Havstad, K.M., R.P. Gibbens, C.A. Knorr and L.W. Murray. 1999. Long-term influences of shrub removal and lagomorph exclusion on Chihuahuan Desert vegetation changes. Journal of Arid Environments 42:155-166.

Havstad, K. M., J.E. Herrick, and W.H. Schlesinger. 2000. Desert rangelands, degradation and nutrients. PP 77-87 in O. Arnalds and S. Archer (editors). Rangeland Desertification. Kluwer Academic Publishers, Dordrecht.

Herrick, J.E., K.M. Havstad, and D.P. Coffin. 1997. Rethinking remediation technologies for desertified landscapes. Journal of Soil and Water Conservation 52: 220-225.

Herrick, J.E., M.A. Weltz, J.D. Reeder, G.E. Schuman, and J.R. Simanton. 1999. Rangeland soil erosion and soil quality: role of soil resistance, resilience, and disturbance regime. in: Soil Quality and Soil Erosion, Soil and Water Conservation Society, Ankeny, IA.

Holechek, J.L., R.D. Pieper, and C.H. Herbel. 1989. Range Management: Principles and Practice. Prentice Hall, Englewood Cliffs, NJ.

Howes, D.A. 1999. Modeling runoff in a desert shrubland ecosystem, Jornada Basin, New Mexico. Ph.D. Dissertation, State University of New York at Buffalo (A.D. Abrahams, advisor).

Howes, D.A. and A.D. Abrahams. In Review. A stochastic model of infiltration on a spatially varied hillslope. Water Resources Research.

Huenneke, L.F. 1996. Shrublands and grasslands of the Jornada Long-Term Ecological Research Site: desertification and plant community structure in the northern Chihuahuan Deesert. PP 48-50 in J.R. Barrow, E.D. McArthur, R.E. Sosebee and R.J. Tausch (editors). Proceedings: symposium on shrubland ecosystem dynamics in a changing environment. USDA Forest Service, Intermountain Research Station, Ogden, UT.

Huenneke, L.F. In press. Biodiversity in desert ecosystems of the future: Responses to climate change and desertification. in O.E. Sala, F.S. Chapin, and E. Huber-Sanwald (editors). Future Scenarios of Biodiversity: Biological Responses to Global Change. Springer-Verlag, New York.

Huenneke, L.F. and I. 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 (editors). Functional Role of Biodiversity: A global perspective. John Wiley and Sons, New York.

Huenneke, L.F., D. Clason and E. Muldavin. In review. Spatial heterogeneity in Chihuahuan Desert vegetation: implications for sampling in semiarid ecosystems. Journal of Arid Ecosystems.

Kerley, G.H. and W.G.Whitford. 1994. Desert dwelling small mammals as granivores:

intercontinental variations. Australian Journal of Zoology 42: 543-555.

Lauenroth, W. K., and O. E. Sala. 1992. Long-term forage production of North American shortgrass steppe. Ecological Applications 2: 397-403.

Marticorena, B., G. Bergametti, D. Gillette, and J. Belnap. 1997. Factors controlling threshold friction velocity in semiarid and arid areas of the United States. Journal of Geophysical Research 102: 23277-23287.

Michalek, J.L., E.S. Kasischke, N.A. Miller, J.E. Colwell, N.E.G. Roller, and W.H. Schlesinger. In review. Relationships between vegetation cover, albedo and radiant temperature in arid and semi-arid lands. Remote Sensing of the Environment.

Miller, R.E. and L.F. Huenneke. In press. Demographic variation within a desert shrub, Larrea tridentata, in response to a thinning treatment. Journal of Arid Environments.

Monger, H.C. 1999. Natural cycles of desertification in the Chihuahuan Desert, North America. pp 209-223 in: Proceedings of the Fifth International Conference on Desert Development. Texas Technological University Press, Lubbock, TX.

Monger, H.C., L.A. Daugherty, W.C. Lindemann, and C.M. Liddell. 1991. Microbial precipitation of pedogenic calcite. Geology 19: 997-1000.

Monger, H.C., D.R. Cole, J.W. Gish, and T.H. Giordano. 1998. Stable carbon and oxygen isotopes in Quaternary soil carbonates as indicators of ecogeomorphic changes in the northern Chihuahuan desert. Geoderma 82: 137-172.

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.

Nash, M.S., P.J. Wierenga, and A. Gutjahr. 1991. Time series analysis of soil moisture and rainfall along a line transect in arid rangeland. Soil Science 152: 189-198.

Neave, M. 1999. Impact of small mammal disturbances on water and sediment yields in the Jornada Basin, southern New Mexico. Ph.D. Dissertation, State University of New York at Buffalo (A.D. Abrahams, advisor).

Ni, W. and X. Li. In press. A coupled vegetation-soil bidirectional reflectance model for a semi-arid landscape. Remote Sensing of the Environment.

Noy-Meir, I. 1973 . Desert ecosystems: Environment and producers. Annual Review of Ecology and Systematics 4: 25-51.

Parsons, A.J., J. Wainwright, P.M. Stone and A.D. Abrahams. In press. Transmission losses in rills in dryland habitats. Hydrological Processes.

Parton, W.J. 1978. Abiotic section of ELM. pp 31-53 in G.S. Innis, Grassland Simulation Model, Ecological Studies 26, Springer-Verlag, New York, NY.

Parton, W.J., J.W.B. Stewart, and C.V. Cole. 1988. Dynamics of C, N, P and S in grassland soils: a model. Biogeochemistry 5: 109-131.

Peters, D.P.C. In press. Climate variation and simulated patterns in seedling establishment of two dominant grasses at their acetone. Journal of Vegetation Science.

Peters, D.P.C. and J.E. Herrick. Submitted. Ecological consequences of climate change: plant-soil feedbacks and ecosystem response. Global Change Biology.

Peters, D.P.C. Submitted. Key processes limiting recruitment for two dominant grasses with different growth forms. Journal of Ecology.

Rango, A., J.C. Ritchie, W.P. Kustas, T.J. Schmugge, K.S. Humes, L.E. Hipps, J.H. Prueger, K.M. Havstad. 1998. JORNEX: a multidisciplinary remote sensing campaign to quantify plant community/atmospheric interactions in the northern Chihuahuan Desert of New Mexico. Chapter 2.7 in Proc. American Meteorological Soc. Meeting, Phoenix, AZ.

Reynolds, J.F., R.A. Virginia, P.R. Kemp, A.G. DeSoyza and D.C. Tremmel. 1999. Impact of drought on desert shrubs: Effects of seasonality and degree of resource island development. Ecological Monographs 69: 69-106.

Schlesinger, W.H. and C.S. Jones. 1984. The comparative importance of overland runoff and mean annual rainfall to shrub communities of the Mojave Desert. Botanical Gazette 145: 116-124.

Schlesinger, W.H. and A.M. Pilmanis. 1998. Plant-soil interactions in deserts. Biogeochemistry 42: 169-187.

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.

Schlesinger, W. H., J.R. Reynolds, G.L. Cunningham, L.F. Huenneke, W.M. Jarrell, R.A. Virginia, and W.G. Whitford. 1990. Biological feedbacks in global desertification. Science 247: 1043-1048.

Schlesinger, W.H., A.D. Abrahams, A.J. Parsons, and J. Wainwright. 1999. Nutrient losses in runoff from grassland and shrubland habitats in southern New Mexico: I. Rainfall simulation experiments. Biogeochemistry 45: 21-34

Schlesinger, W.H.. T.J. Ward, and J. Anderson. In Press. Nutrient losses in runoff from grassland and shrubland habitats in southern New Mexico. II: Field plots. Biogeochemistry.

Wainwright, J., A.J. Parsons, and A.D. Abrahams. 1999. Rainfall energy under creosotebush. Journal of Arid Environments 43:111-120.

Wondzell, S.M., G.L. Cunningham, G.L., and B. Dominique. 1996. Relationships between landforms, geomorphic processes, and plant comunities on a watershed in the northern Chihuahuan Desert. Landscape Ecology 11: 351-362.

Wright, R.G. 1972. A demographic study of a semiarid grassland. Colorado State University Ph.D. Dissertation, Fort Collins, Colorado.

Zeisset, M. 1998. Effect of plant community structure on insect community structure in the Chihuahuan Desert. M.S. Thesis, New Mexico State University (L.F. Huenneke, advisor).

Site Management

Leadership and administration

With this proposal and set of collaborating investigators, the Jornada Basin LTER program continues its pattern of evolutionary change in project leadership and scientific personnel. Laura Huenneke, Kris Havstad, Debra Peters, and Curtis Monger are assuming the roles of lead principal investigators; thus the base grant will move from Duke University back to Las Cruces and NMSU. This group of lead PI's includes representation of both the USDA-ARS (Havstad, Peters) and NMSU (Huenneke, Monger), the latter including faculty from both Arts & Sciences and the College of Agriculture. Thus our leadership reflects the true collaboration and partnership of the Las Cruces-based institutions forming the foundation of the Jornada effort. Bill Schlesinger of Duke will continue active involvement both in the scientific program and as a member of our executive committee, contributing stability to our leadership.

We plan to continue sharing responsibilities for outreach and communication. Bill Schlesinger will continue to be our main contact with Washington and national research agency collaborations. Huenneke and Havstad will serve as liaisons with local and regional agencies and institutions. Havstad and his JER colleagues will coordinate with the USDA and other national resource management agencies. Debra Peters, with her extensive collaborations at the Sevilleta and Shortgrass Steppe LTER sites, will be our primary contact with the LTER Network, e.g, in attending most Coordinating Committee meetings. Curtis Monger will serve as a direct liaison with NMSU's College of Agriculture and the Agricultural Experiment Station.

The full membership of the Jornada Basin LTER group brings into formal collaboration several researchers who became involved with Jornada research during the LTER III funding cycle. These include Tony Parsons (Leicester University) and John Wainwright (Kings' College, London), originally working under a subcontract with Athol Abrahams; and Debra Peters and Jeff Herrick, who joined the ARS Jornada Experimental Range during the period of LTER III. Finally, Al Rango of the ARS-Beltsville is joining the group to formalize the link between previous ARS-funded JORNEX work and the LTER remote sensing effort.

An executive committee of four investigators (Havstad, Huenneke, Peters, and Schlesinger) will have ultimate authority in decisions of allocating resources or setting policies. Our site manager, John Anderson, makes decisions about the use of lab, office, or field facilities by visiting and student researchers, and consults with the executive committee as needed. We anticipate formal reassessments of the progress made in our various research efforts at least every other year during the LTER IV funding cycle, with the possibility of reallocation of funding among projects or participants. We have learned the importance of being able to respond to opportunity when new researchers or new research opportunities present themselves, or when the commitment of an individual to the program changes. These progress assessments, and other group discussions of policies and research direction, will take place at PI meetings held in conjunction with the annual Friends of the Jornada symposium in Las Cruces each summer.

We expect that most LTER staff members (e.g., John Anderson, site manager, and the data management and field technician staff members) will continue to be employed through NMSU's Department of Biology. Huenneke will serve as supervisor for Anderson, who in turn supervises LTER staff. Huenneke (through Anderson) and Havstad will serve as co-supervisors for those employees supported jointly by both NMSU and the ARS-JER, such as our GIS specialist, Barbara Nolen.

Communication

Since early in LTER II, Jornada researchers from multiple institutions have had to devise ways of staying in close communication. The annual Friends of the Jornada symposium, held each summer, is still one of the most important of these – though attendance includes many scientists and students beyond the LTER. Attendance has been 100 or more for the past several years. Bill Schlesinger initiated and continues to edit a semi-annual newsletter, *Jornada Trails*, for researchers, administrators, and agencies interested in Jornada activities. Email, of course, is quite important in linking collaborators (e.g., contact with our U.K. colleagues). Finally, we use conference telephone calls when the immediacy of issues justifies them.

In addition to continuing these activities, we intend to initiate a new mechanism for promoting interactions among Jornada researchers. We propose to teach a graduate course in the ecology of semi-arid rangeland systems, cross-listed in NMSU's Biology and Agronomy & Horticulture departments. Both local and visiting researchers, from outside the LTER program as well as LTER participants, will be invited speakers. The course will emphasize both the considerable history of ecological research conducted at the Jornada since 1915 and the diversity of scientific questions and management applications being studied today. We hope to use this course as a vehicle for bringing non-Jornada researchers to Las Cruces for interaction with LTER scientists, staff, and students, and for gaining valuable outside perspectives on our program.

Staff, facilities, and resources

The Jornada LTER employs three full-time office staff (Site Manager John Anderson, Network/Data Manager Ken Ramsey, and GIS Specialist Barbara Nolen). During LTER III we have employed two field/lab technicians. This level of support has not been sufficient for the increasing workload; thus we propose to employ three full-time field technicians for LTER IV. In addition, LTER funding and a commitment from NMSU's College of Arts & Sciences to Huenneke will support an additional technician dedicated largely to the plant diversity experiment and other plant community work. We also employ student and temporary employees as seasonal workers for intensive field periods, and for data entry. The ARS will continue to provide field support on collaborative projects including the multiple stressor and fire studies.

Office and laboratory facilities are currently housed in Foster Hall, home of NMSU's Biology Department. Field workers use Biology Department motor vehicles for access to the Jornada. Expanded office, GIS, and laboratory facilities are planned for the Jornada LTER program staff in the new ARS-Jornada Experimental Range headquarters building. This $7.4 million facility is being constructed on the NMSU campus with planned completion in 2001.

Field sites are located on the ARS-Jornada Experimental Range and the adjacent NMSU facility, the Chihuahuan Desert Rangeland Resource Center (CDRRC). Together these properties represent > 100,000 ha dedicated to long-term and experimental research in semi-arid rangelands. Researchers have access to field lab and workshop facilities at the ARS-JER field headquarters on site; the connectivity proposal funded in 1999 provides reliable network access to this site and will facilitate remote data collection and downloading to campus computers.

Site manager John Anderson serves as a primary contact for visiting researchers. He facilitates their identification of suitable field sites, allocates available office and lab space, furnishes them with computer network access, and assists them with finding local housing. NMSU and ARS-JER have provided a set of 10 cellular phones, available for checkout to visitors to enable emergency contact with campus or emergency personnel when in the field.

Information Management

Our information management system comprises three major components: the formal data management protocols, the acquisition and management of spatial data, and the provision of networking and computing services. John Anderson (Jornada site manager), Barbara Nolen (GIS specialist), and Ken Ramsey (data manager and computer systems manager) collaborate in providing this support to the Jornada program. In the 'Results of Prior Support' section, above, we described the datasets currently available to interested researchers through our data management system.

Data Management Protocols

The purpose of data management for the Jornada LTER is to provide protocols and services for data collection, verification, organization, archival, and distribution. Procedures are conducted in accordance with recommendations and guidelines developed by the LTER Data Managers Group.

Data managers are involved with researchers from the initial stages of sampling design and data collection, through the data entry and verification phase, to the archiving and distribution of the data. This encourages maximum interaction between researchers and data management personnel to avoid confusion and potential loss of data.

Site and Data Manager involvement begins during the Project Design phase with the completion of the Jornada Notification of Research form by the researcher prior to the start of work; this alerts both Site and Data Manager to the new study and potential LTER data sets. Upon initiation of a new study, the researcher completes Project Documentation which provides the second level of "meta-data" documentation.

In the Data Collection phase, the data manager helps researchers design field and laboratory data sheets that facilitate data entry and analysis. Prior to data entry the investigator completes Data Set Documentation to provide the meta-data that fully describe the data set. Both Project and Data set documentation are considered integral parts of the data set; both are provided with the data set when it is requested or obtained from our Web site. Data entry programs error-check and verify data as they are entered. Computer files are subjected to further verification by graphing and/or error-checking programs, and/or examination by field investigators. Final quality assurance of the data rests with the investigator who submits data for inclusion in the Data Management System. Direct communication with the Site Manager, John Anderson, or through a collaborating Jornada LTER PI, is used to encourage the timely submission of documentation and of data by researchers.

Error-checked data files are stored with associated documentation files on floppy disks and on hard disk on the file server. Backup data files are maintained as "hard copy" and electronically on multiple floppy disks, on read/write 30-yr magneto-optical disks, and on CD-R media. Image data are archived on 8mm tape. Routine tape backups of the file server containing the data are done daily, weekly, and monthly. Off-site copies are maintained of routine backup tapes, floppy disks, and magneto-optical disks elsewhere 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. This includes use of ftp, Telnet, email, and World Wide Web (WWW) capabilities.

Online availability of our LTER data is through our WWW site, which includes a catalog of Jornada data sets with "hot-links" to Project and Data Set Documentation and data sets. Policy statements regarding submission of data, data access, and data acknowledgment may be found on our web page, http://jornada.nmsu.edu. In addition to online availability of data, requests received for most 'restricted' datasets are usually responded to within 24 hours with data sent via ftp, e-mail, hard-copy, or on floppy disk, as appropriate. Ongoing LTER Network participation includes the LTER Data Managers Data Table of Contents project and the Database Climate project as well as representation and participation at the annual Data Managers Meeting. Finally, we are steadily working to recover and incorporate datasets from earlier funding cycles (e.g., LTER I) and earlier projects (e.g., the IBP) into today's information management system.

The Jornada LTER site offices and labs will be moving into the planned Jornada Experimental Range USDA-ARS headquarters building on the NMSU campus, upon the building's completion in 2001. Jornada LTER and JER information management efforts will be further integrated using our established LTER protocols. It is anticipated that the ARS will hire an additional GIS specialist and data manager at that time to support these efforts. The building will be equipped with a GIS lab for the joint LTER-ARS program.

GIS and Remote Sensing

The Jornada GIS provides digital data and images to support research efforts. The current GIS archive includes data layers for boundaries, infrastructure, elevation, climate instrumentation and research locations. Our image archive includes AVIRIS, AVHRR, Landsat, Daedalus and aerial photography with continued participation in several image aquisition programs. The most recent data layers created in digital form include the 1928-29 vegetation, 1998 vegetation, Geologic Map 57 and the Desert Soils Project (Fig. 1.8, 1.9, 1.10). These projects are being carried out in cooperation with Water Resources Research Institute, New Mexico Bureau of Mines and Mineral Resources, USDA Natural Resource Conservation Service.

We will continue to coordinate and integrate GIS and remote sensing datasets with cooperative agencies. Future tasks include the addition of meta-data to existing data layers and images. Efforts are also continuing to provide maps and meta-data in a queryable format over the Internet via the map server. Spatial data and meta-data will also be made available for download. A geomorphology mapping project will continue the Desert Soils Project northward across the Jornada Basin. Mapping efforts continue to add current and historic infrastructure and research site locations to the archive using GPS. These data layers are crucial both as general context for any new or ongoing studies and as the essential foundation for our current emphasis on linking vegetation change with geomorphological features.

Computer and Network Support

Local Area Network

The Jornada LTER provides computers for use by data management staff, field technicians and researchers. Visiting researchers use Jornada LTER lab computers for accessing email and for data acquisition and processing. As the Jornada LTER local area network (LAN) grows, network performance becomes a greater concern. Recent upgrades to LAN cabling, hubs, and network cards have dramatically increased performance. In addition, the LAN is ready to move to Fast Ethernet when the NMSU campus backbone is upgraded from Ethernet.

The growing electronic archive of remote sensing images will require an increase in the site's LAN storage capacity. Current storage space allows copying image data files to and from other media, such as 8-mm data tapes and CD-R media. Previously, the main focus has been to collect and archive remote sensing data (images and files) for later analysis. With the addition of a Remote Sensing researcher (Al Rango) to the Jornada LTER, analyzed data will also be archived on the Jornada LTER file server. As these remote sensing data are used to expand research from a patch to a landscape model, the LAN storage space required to analyze and archive this data will increase rapidly.

Network security is an important aspect of maintaining the Jornada LAN. All authentication services for the LAN are performed by the file server, running Novell Netware 5. All servers and workstations are virus-protected with McAfee Netshield or VirusScan software. Moving the web server to a separate PC will provide additional security for the Jornada LTER Web Server, File Server, and LAN. The stand-alone web server is operational and will be placed online upon completion of the redesigned web site. The next step will be to implement a hardware firewall.

Web Site

LTER personnel are currently working on the conceptual design of an enhanced version of the Jornada LTER web site. The implementation of this design will begin late in LTER III, continuing into the new funding cycle. The new web site will have the added capability to query data and meta-data, and serve maps over the Internet. Meta-data and/or data from the bibliography, personnel, research projects, research data sets (spatial and non-spatial), species lists, and herbarium databases will be queryable over the Internet. The Jornada LTER Internet Map Server is being developed concurrently and will serve maps and associated meta-data over the Internet.

The Jornada LTER Information Management System (IMS) is also being redesigned to automate and provide stronger QA/QC aspects through database and web interfaces. Some new features will be added during LTER III to the current web site as they are developed, such as the ability to complete Notification of Research forms via the Internet. Most features of the new IMS will be developed and implemented during the LTER IV funding cycle and added to the redesigned web site. The current IMS operates with mostly ASCII text files; the new IMS will be constructed using relational databases. The new IMS will allow data management personnel to manage, maintain, and query database tables containing spatial and non-spatial meta-data about Jornada LTER research projects, both historic and ongoing. All data and associated meta-data will still be archived in ASCII text files. These archived files will be used to verify that database table content has not changed prior to updating table data. Portions of the IMS will be available for meta-data submission over the Internet, such as the Jornada Notification of Research form. Most of the IMS will only be accessible over the Intranet to data management personnel, requiring user authentication prior to gaining access to the system. In sum, our recent investment of supplement funding and our plans for upgrading hardware, protocols, and web site design will ensure flexible, functional, and accessible data management for the Jornada Basin LTER.

Outreach Efforts during Jornada LTER III

Outreach efforts of the Jornada LTER program have evolved into a diverse collection of activities during our recent funding cycle. Our objective has been to educate and engage both the general public and specific groups. Outreach activities occur in six categories: education, public seminars, print media, video media, focus group, and clientele services.

Education

Our educational activities are primarily of two types: field days and classroom visits for K-12 school children, and annual five-week science workshops for 4 to 6 K-12 teachers. During 1999, 3000 K-12 school children either visited Jornada field sites or were visited by Jornada scientists or staff in their classrooms. Field days include a series of hands-on type demonstrations at stations illustrating various aspects of desert ecology and desert agriculture. Topics include animal ecology, soil genesis, ruminant digestive physiology, plant physiology, plant community ecology, and climatology. Content is adjusted for grade level. Due to high demand, we have established a formal collaboration with a non-profit organization, the Chihuahuan Desert Nature Park, to administer our growing K-12 education program. Resources from the NSF Schoolyard LTER grant, USDA-ARS, and the World Wildlife Fund support our program. Volunteers and NMSU student interns assist with field trips, classroom visits, and curriculum development.

Our teacher intern program has been supported for the past three years by an NSF and USDA-ARS grant entitled "First Step". The program provides participants with a stipend to develop science-based curricula for the classroom. Teachers are selected through a competitive process. They spend three weeks working with Jornada staff and two weeks in College Station, TX, with other First Step teachers sharing their experiences. One of our First Step teachers, Sarah Torres, was named the 1999 New Mexico science educator of the year. She currently teaches science at a Las Cruces middle school participating in our Schoolyard LTER program.

Public presentations

We routinely present seminars throughout the region for the general public on topics of desert ecology and management. Attendance at these public events varies from 10 to 125 people. Jornada scientists are often asked to synthesize existing research information, especially on controversial topics. One seminar series on livestock grazing has been presented upon request in public settings in Santa Fe, Roswell, Silver City, and Albuquerque, NM, to over 300 people from 1997 to 1999. Two of our PI's, Bill Schlesinger and Laura Huenneke, were selected for the first cohort of Fellows in the Aldo Leopold Leadership Program, which provided two weeks of intensive training in communication skills, media relations, and interactions with policy-makers.

Print media and general interest publications

Jornada scientists have worked with newspaper and magazine writers and newsletter editors in communicating our research objectives and results. An overview article on the Jornada LTER was published in the national magazine DISCOVER in 1995. Feature stories on the Jornada have been published in regional newspapers (Las Cruces *Sun News* and the El Paso *Times*), and Jornada scientists are frequently contacted to provide scientific background or quotes on particular issues of regional interest. The LTER program has been featured both in the NMSU alumni newsletter, the *Aggie Panorama*, and in the Duke University alumni magazine. Several stories summarizing aspects of Jornada research have also been published over the past five years in the ARS monthly magazine, *Ag Research*, most recently in December 1999. Our researchers' newsletter, *Jornada Trails*, is circulated widely to university administrators and agency personnel in the region.

Video productions

The Agricultural Communications Department at NMSU has an award-winning video production unit. Jornada scientists have worked with this video unit on three high-quality videos. The first was a 30-minute program on the geomorphologic history of the middle Rio Grande. The second was a 60-minute documentary funded by the International Arid Lands Consortium that detailed human interactions in the southwestern U.S., Australia, and Israel. This production highlighted long-term research at the Jornada and was broadcast on public television stations across the U.S. during 1998-99. The most recent video production was a 30-minute production, written and narrated by Curtis Monger, that described the development of desert soils. The excellent production relied heavily on the history of research data collected in the Jornada basin.

Jornada focus group

In 1995, Jornada ARS scientists invited people from a diversity of organizations and interest groups to form a standing focus committee. These people represent groups with specific interests in the basic science and the applications of science developed at the Jornada. The group meets twice per year to be briefed on current research progress by ARS and other LTER scientists, and to provide input on future research directions. Organizations represented include the Sierra Club, The Nature Conservancy, the World Wildlife Fund, the Bureau of Land Management, the Natural Resource Conservation Service, the New Mexico State Lands Office, the Conservation Fund, the Animas Foundation, the New Mexico Cattle Growers, and the general scientific community. This committee has been extremely effective in recent years in conveying the importance of the research at the Jornada to their organizations and to members of Congress. Several of these organizations directly collaborate in research related to LTER objectives.

Clientele

The 85-year record of research in the Jornada basin is a well-recognized legacy that draws visitors from around the world. Jornada scientists and staff conduct over 30 tours annually upon request. Often these tours are for individuals or organizations that can be regarded as clients of our research information. These clients include foreign scientists, cattle producers, and land management agency personnel. For example, in 1999, National Park Service personnel requested a special workshop and tour at the Jornada for US and Mexican park personnel to learn about desert ecology and new technologies for monitoring desert grasslands and shrublands. We provide these workshops in both English and Spanish. In March 2000, the BLM National Science Coordinating Committee has requested a special tour at the Jornada; research at the Jornada has direct application to BLM's chief management concerns in the southwest.