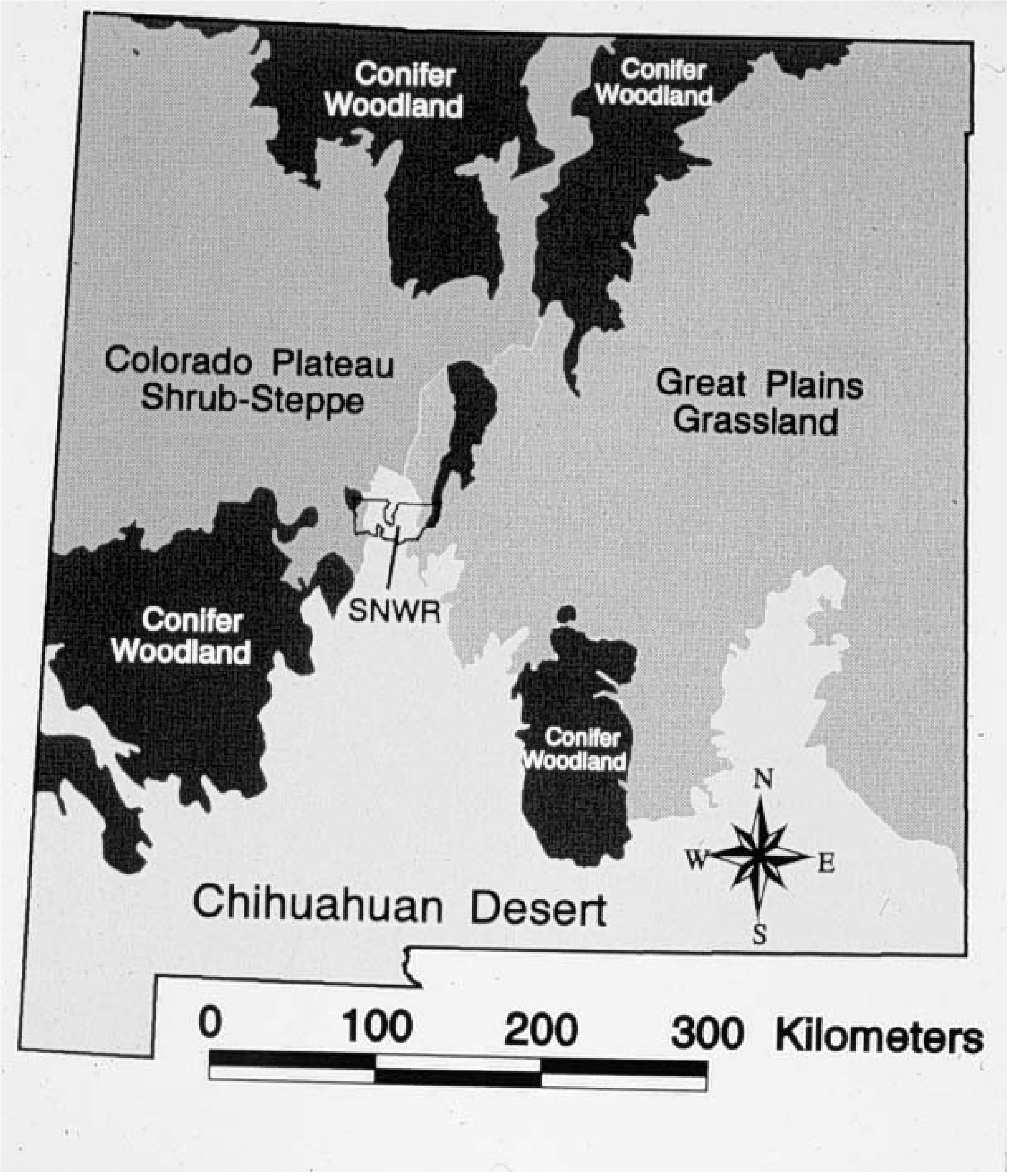
SEVILLETA LTER III:
LONG TERM ECOLOGICAL RESEARCH IN A BIOME TRANSITION ZONE



A Proposal Submitted to the National Science Foundation

January 31, 2000

Integrated Studies
of
Ecotones/Transitions

Flora
Competition
Productivity
Mortality
Natality
Facilitation

Fauna
Granivory
Seed Dispersal
Disturbance
Herbivory
Predation

Topography

Climate Dynamics

Trophic Studies

Microbes
Decomposition
Mycorrhizae
Microbiotic Crusts

Hydrology

Soils

Energy Studies

Nutrient Dynamics

Remote Sensing

Modeling

Grazing

Fire

Air Pollution

At Multiple Temporal and Spatial Scales

A collaborative effort among scientists from:

University of New Mexico
New Mexico State University
New Mexico Tech
University of Arizona
University of Colorado
U.C. Riverside

and

U.S. Fish and Wildlife
USGS (Tucson)
U.S. Forest Service
Los Alamos Natl. Lab
Sandia Natl. Lab
ARS Jornada Exp. Sta.
The Nature Conservancy

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Project Summary

The Sevilleta Long Term Ecological Research (LTER) Program, established in 1988, conducts research on ecological processes and responses to climate dynamics in a biome transition zone in central New Mexico. The major research site is the Sevilleta National Wildlife Refuge, operated by the U.S. Fish & Wildlife Service (FWS). The multi-disciplinary research group comprises 34 scientists from 10 universities and numerous research agencies, including FWS, The Nature Conservancy, U.S. Geological Service, USDA Forest Service, USDA Agriculture Research Service, DOE Los Alamos National Laboratory, and DOE Sandia National Laboratory. The primary goal of the LTER Program is to develop and test a hierarchical model of controls and constraints on the movements of biotic assemblages at the edges of their distributions. These movements occur as a result of complex interactions among a large number of abiotic and biotic variables, at a wide range of spatial scales, and over time periods ranging from minutes to centuries. The Sevilleta LTER models and experiments address the relative roles of the major controlling variables, and allow predictions of changes in the structure and functioning of biome transition zones that would result from natural (e.g., climate) and anthropogenic (landuse, grazing, fire) perturbations. Of particular interest is the role of moisture availability (drought cycles, El Niño/La Niña episodes, Pacific Decadal Oscillations) in driving the distributional expansion and contraction of C_3 and C_4 plant species (trees, shrubs, grasses) over decadal time frames, and the resulting changes in local and landscape level ecological processes. The results of these studies will provide a greater understanding of the physical and biological processes that govern the dynamics of the major ecosystems in central New Mexico, factors that lead to desertification processes, and contribute to improved understanding and management of the environment for sustainable human use and development.

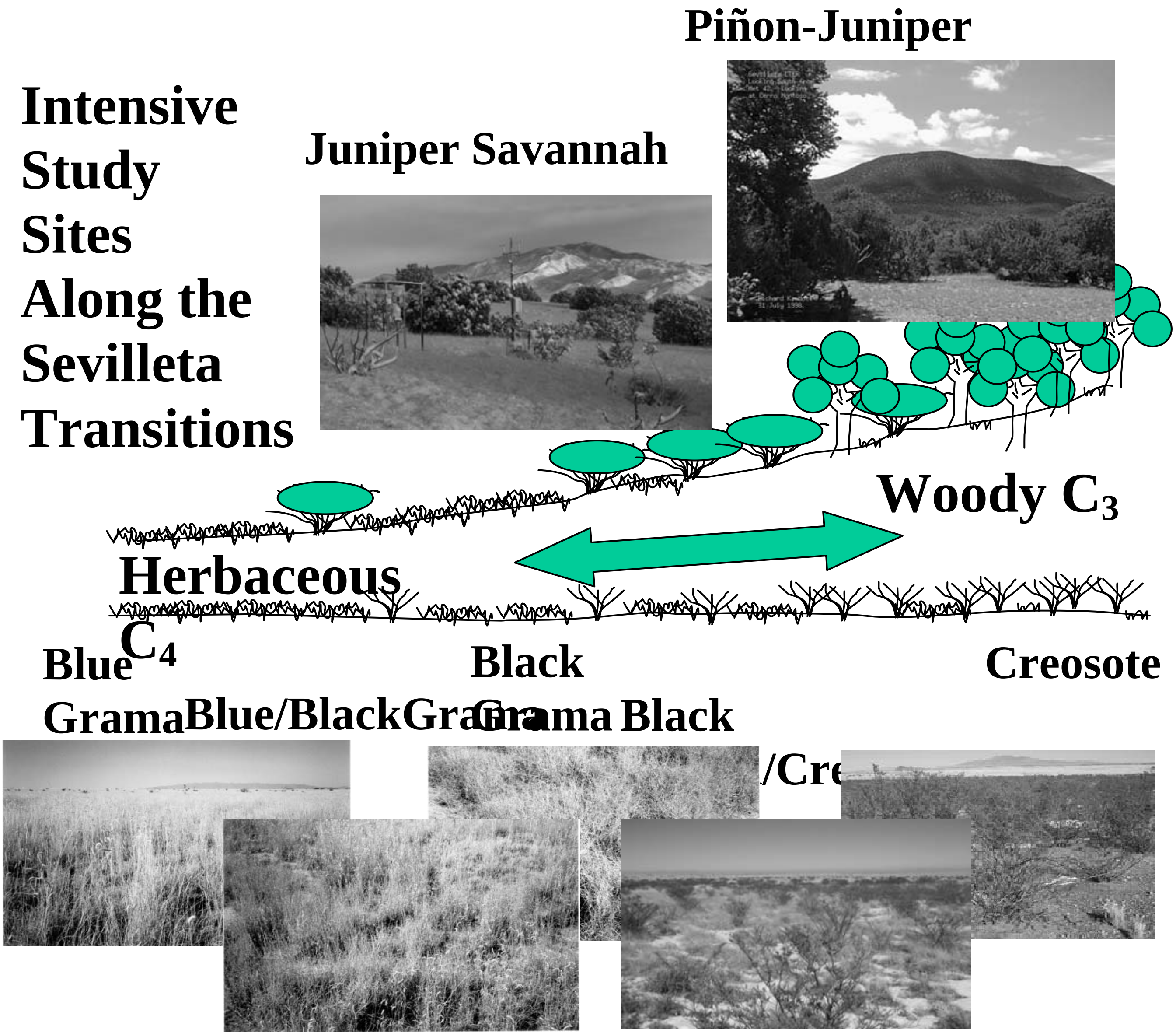


Figure I.1. The ecotones and transitions of the Sevilleta National Wildlife Refuge. We have concentrated our long-term monitoring and experimental research programs to an area of the refuge that contains transitions between flora and fauna of the Chihuahuan Desert, Shortgrass Steppe of the Great Plains, and Mogollon Conifer Woodland (Piñon-Juniper). Creosote (*Larrea tridentata*) ranges from a community dominant (Chihuahuan) to scattered individuals and patches in a Black Grama (*Bouteloua eriopoda*) grassland (also Chihuahuan flora). Black grama ranges from a community dominant to a mosaic of patches with Blue grama (*Bouteloua gracilis*) in the transition between Chihuahuan and Shortgrass Steppe perennial grasslands. The transition from perennial grassland to Juniper (*Juniperus monosperma*) savanna and into Piñon (*Pinus edulis*) and Juniper woodlands reflects an elevational gradient. The transitions also reflect a general C_3 woody species to C_4 herbaceous grassland.

Reviewers: A special page has been set up to help you find the web links identified in the proposal (http://sevilleta.unm.edu/reviewers).

I. Results from Prior Support

I.1. Overview: The Sevilleta (SEV) LTER Program has focused on a suite of ecological hypotheses concerning climate dynamics and the responses of organisms in a biome transition zone in central New Mexico. The area of the SEV straddles several major biome transitions (**cover**), and its large size (100,000 ha) is important for multiscale studies that range from genetics and physiology at the organismal level to the dynamics of the transition zones themselves. The region is strongly influenced by the El Niño Southern Oscillation (ENSO), with major fluctuations in precipitation on semi-decadal and multi-decadal time scales.

The overall research scheme of the SEV LTER is organized around the relationship of energy and water as limiting factors for ecological processes in the various ecosystems of central New Mexico. The dynamics of energy and moisture inputs at various spatial and temporal scales serve as drivers (both direct and indirect) for the observed patterns and dynamics of SEV ecosystems, communities, and populations. We are developing a series of models that can simulate biological responses to moisture and energy inputs on various scales, from sub-hectare plots to the entire SEV area. When parameterized and calibrated through field measurements and experiments, these models will permit the development of predictive scenarios in which future ecological responses to climate dynamics can be evaluated. The models rely on inputs from our meteorological, hydrological, and vegetation studies, GIS data layers (soils, vegetation map), remotely-sensed and ground-based NPP measurements, estimates of nutrient cycling dynamics, and analysis of the interactions among populations of herbivores, predators, and detritivores.

The SEV program conducts intensive field studies at five "core" research sites, each of which represents a point along the gradients that characterize the transitions (**fig. I.1**). Thus, we are able to compare the ecological processes observed at each site along this ecosystem gradient to different, though nearby, sites on the SEV, as well as to sites in similar ecosystems throughout the Southwest. Our results from the northern limit of the Chihuahuan Desert on the SEV are being integrated with, and contrasted to, results from the Jornada LTER and the Mapimi MAB Station, Durango, Mexico. The grassland studies on SEV are integrated with comparable studies at the Short Grass Steppe and Jornada LTER sites. Our juniper savanna and Piñon-Juniper woodland research is coordinated with similar studies being conducted at Bandelier National Monument in northern New Mexico. Within the SEV, we are comparing the structure and functioning of the different ecosystem types as a result of climate dynamics at time scales ranging from seasonal fluctuations to decadal and longer cycles of droughts and El Niño/La Niña events. Finally, as longer-term changes occur in climate, human impacts (pollution, fires, land use), and species composition (invasions and extirpations), we will observe the nature of ecosystem change, determine the patterns and constraints of ecotonal movements, and evaluate the impacts of these changes on both "natural" and human communities. Within each of our major study sites, we have developed energy and water models and made substantial progress on plant growth models. These models provide the framework for our "core" LTER studies.

I.2. Field Studies: In concert with the model development, long-term monitoring studies and manipulative experiments test both concepts and model applications of climate factors as constraints on ecological processes within and among SEV ecosystems.

I.2.A. Pattern of inorganic inputs: The SEV LTER maintains nine meteorological stations that acquire continuous data on air and soil temperatures, precipitation, atmospheric relative humidity, wind speed and direction, and solar radiation. Bowen-ratio stations, and

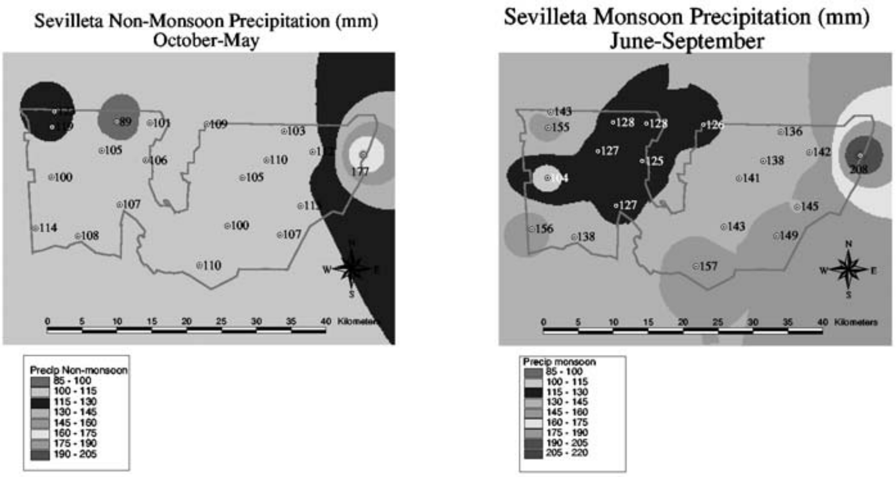
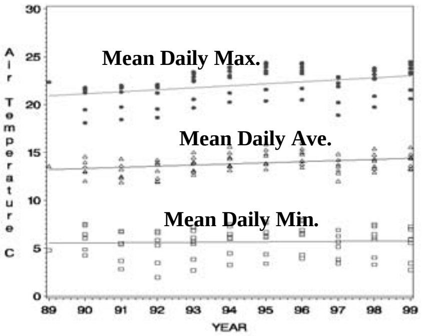
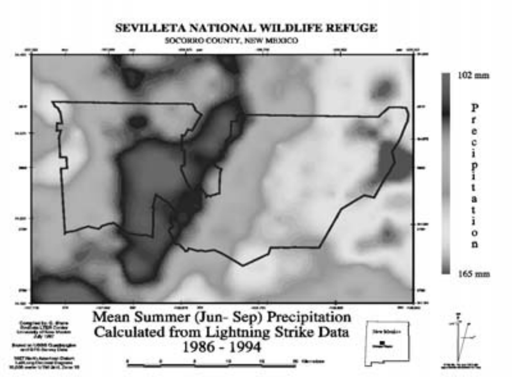
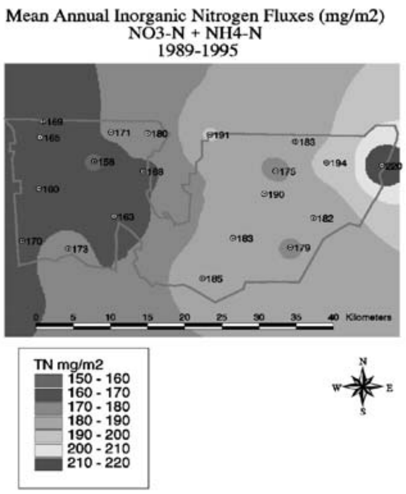


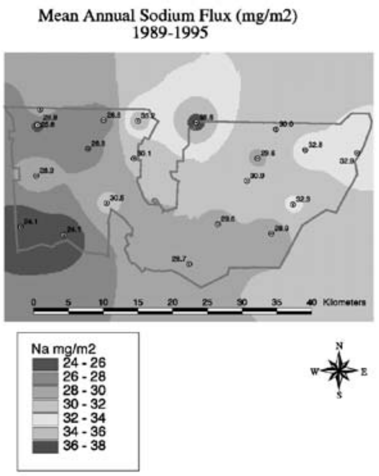
Figure I.2. Average Non-Monsoon (left) and Monsoon (right) precipitation. Monsoon moisture is less correlated with elevation than Non-Monsoon moisture because of the effects of high spatial variability of convective storms during the summer Monsoons.





Lightning locations also estimate precipitation amounts. Higher elevations generally receive more moisture; however, there are areas with long-term patterns of high or low amounts not related to elevation. The spatial variation in precipitation plus higher concentrations of pollutants in air masses that are constrained by mountains on the east side of SEV result in higher amounts of nitrogen deposition on the east side (lower left). Other chemicals show different patterns (e.g., sodium) as a result of local or regional sources and higher concentrations in Non-Monsoonal moisture. Daily maximum temperatures across all weather stations have been oscillating and rising during the decade.





continuously recording TDR instruments evaluate soil moisture and water flux. The pattern and timing of precipitation are critical to the modeling efforts and field research studies conducted at the SEV (Data: **http://sevilleta.unm.edu/research/local/climate**. Precipitation amounts from broad frontal systems leading to the winter storms of New Mexico can be measured with reasonable accuracy in our rain gauges. However, amounts from summer thunderstorms are much more difficult to assess because of the localized nature of rainfall. Hence, we have developed mathematical relationships between lightning strike locations (**fig. I.2**) and total amounts of precipitation (Gosz et al. 1995, Potter et al. 1998). Ongoing studies use weather stations, lightning, NEXRAD and TRMM to estimate precipitation amounts.

Monthly precipitation samples (including two wet-fall/dry-fall collectors) for chemical analyses allow estimates of inorganic nutrient inputs. Results to date indicate a predominantly higher input of inorganic materials in precipitation on the east side of SEV (**fig. I.2**), a location "downwind" of the smog plume from Albuquerque. The spatial patterns of these data are consistent with atmospheric models developed at Los Alamos National Laboratory for the Rio Grande Valley. Atmospheric and precipitation inputs are expected to increase with the human population growth in the Rio Grande Valley north of the SEV. The last decade has had an increase in maximum temperatures suggesting a trend or oscillation.

I.2.B. Pattern and control of primary production: In the initial years of the SEV LTER program, we used a wide variety of satellite-based imagery to estimate spatio-temporal patterns of Aboveground Net Primary Production (ANPP). Ground-truthing efforts, via vegetation clip plots, revealed high variation due to low percent cover. Hence, for our broad-scale studies, we measured spring and summer, species-specific percent cover as a surrogate for NPP. These data were collected at our major research sites, coincident with meteorological and NDVI values (**fig. I.3**). Directly-measured field net primary production (NPP) studies were begun at the major research sites in February 1999, using the same volumetric techniques used at the Jornada LTER site (Huenneke, Clason, & Muldavin Submitted). Species-specific NPP measurements are collected from an array of permanent quadrats located in association with each of the five rodent trapping sites. Production of seeds of major grass species, juniper berries, oak acorns, and Piñon nuts (mast) are also being measured.

I.2.C. Transition vegetation dynamics: Spatio-temporal patterns of species distributions, community organization, and ecological processes have been major thrusts of SEV LTER research, in both theoretical and experimental arenas (Gosz & Sharpe 1989, Gosz 1991a,b, 1992, 1993, 1995, Gosz et al. 1992, Risser 1995, Gosz et al. 1995, Milne et al. 1996, Keitt et al. 1997, Kieft et al. 1998, Minnick & Coffin 2000, Li 2000a,b,c). The SEV transitions have been analyzed (Data: http://sevilleta.unm.edu/data/archive/plant/) using plant cover data from 1 km SEV vegetation transects (Li et al. submitted; **fig. I.4**). Species removal experiments along the grassland-shrubland ecotone are continuing (Peters submitted, Buxbaum in prep.)

I.2.D. Pattern and control of organic matter accumulation in surface layers and sediments: Decomposition rates of dominant SEV plants were measured in the major ecosystems with litterbags from 1989-present. N and C analyses are currently underway for all samples. Soil N availability and potentially mineralizable N have been measured in the SEV grasslands over 10 yr. Both factors demonstrate non-linear patterns and lag effects with climate that are best fit by hyperbolic functions (White & Craig, in prep.). Patterns of microbial activity and soil C and N processing were described (Kieft et al. 1998), and incorporated into a cross-site, continental scale analysis (Zak et al. 1994). In addition, soil erosion bridges are measured at the core sites.

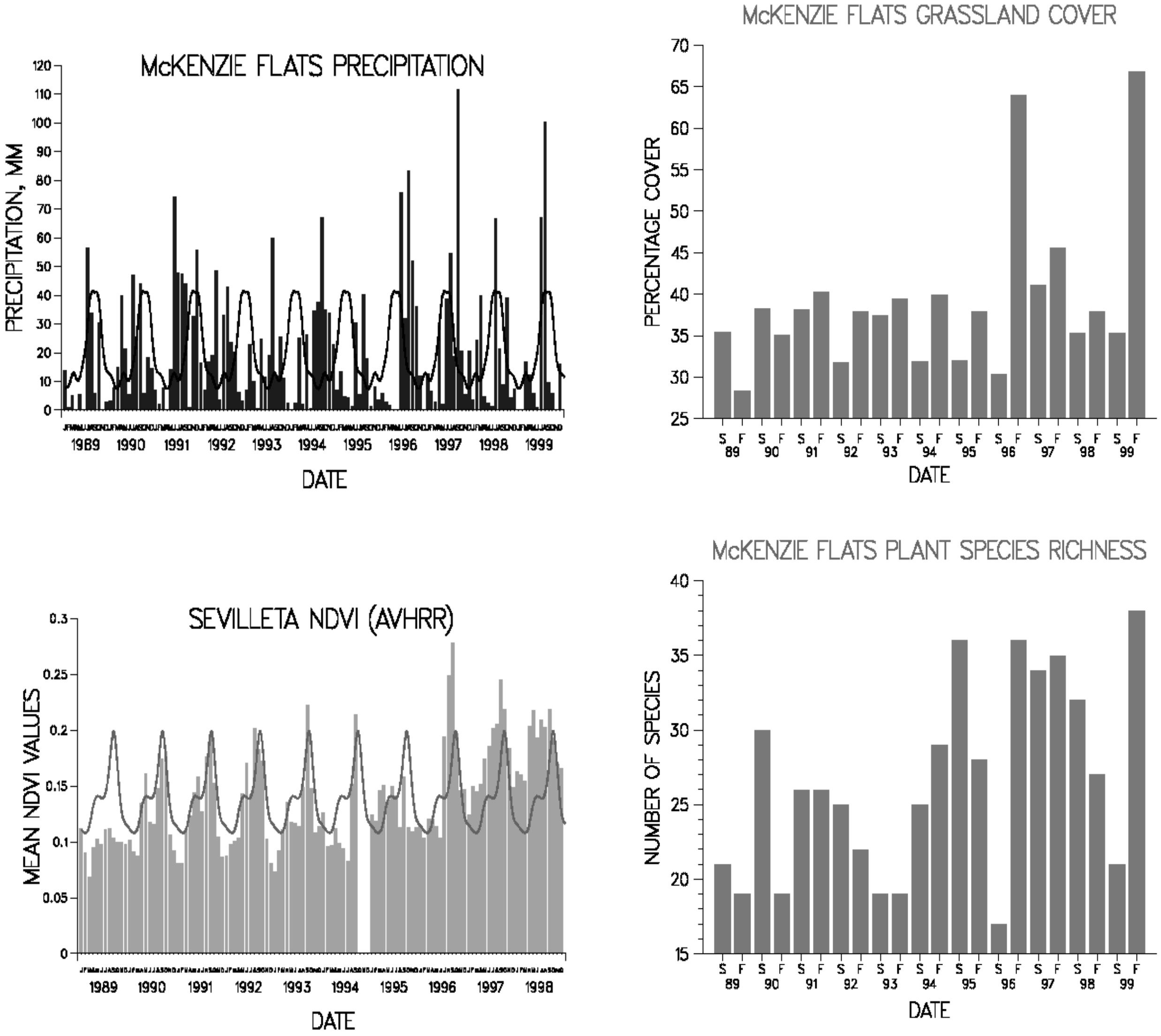


Figure I.3. Precipitation varies dramatically on a seasonal and interannual basis relative to the long-term mean (upper left). Percent cover (by species) was determined seasonally on 400 m to 1 km line intercept transects (upper right). Percent cover relates well to the highest seasonal precipitation amounts but is less well correlated with precipitation during less extreme seasons. Plant diversity is less well correlated with precipitation than is percent cover (lower right). Our long-term archive of AVHRR imagery allows monthly NDVI (Vegetation Indices) that can be related to percent cover (lower left). The drought of 1989 and the very high Monsoon moisture in the later years cause high deviations from the long-term mean (blue line). These data are for the Black Grama – Blue Grama transition located on a large, flat plain referred to as McKenzie Flats.

The soil surface is very dynamic in some locations, with depth losses of 3 cm common. Associated with the bridge measurements are data on soil texture, water holding capacity, organic matter, N mineralization potentials, total N and P, and soil conductivity. The net gain or loss of the soil surface allows calculation of changes in nutrient resources (Data: http://sevilleta.unm.edu/research/local/nutrient/) .

I.1.E. Spatial and temporal distributions of populations. Our research includes studies of vertebrates and invertebrates along our transitions to ascertain: 1) the influence of climate on population dynamics; and 2) the role of animals as trophic drivers regulating vegetation dynamics. A serendipitous result of these studies has been their role in understanding human disease epidemics in the Southwest. Diversity of vertebrates is high, due to the transitional nature of the region's ecosystems (Parmenter and Van Devender 1995, Parmenter et al. 1995, Frey & Yates 1996), though relationships with ecosystem NPP are less clear (Waide et al. 2000, Data: http://sevilleta.unm.edu/data/archive/animal/ .

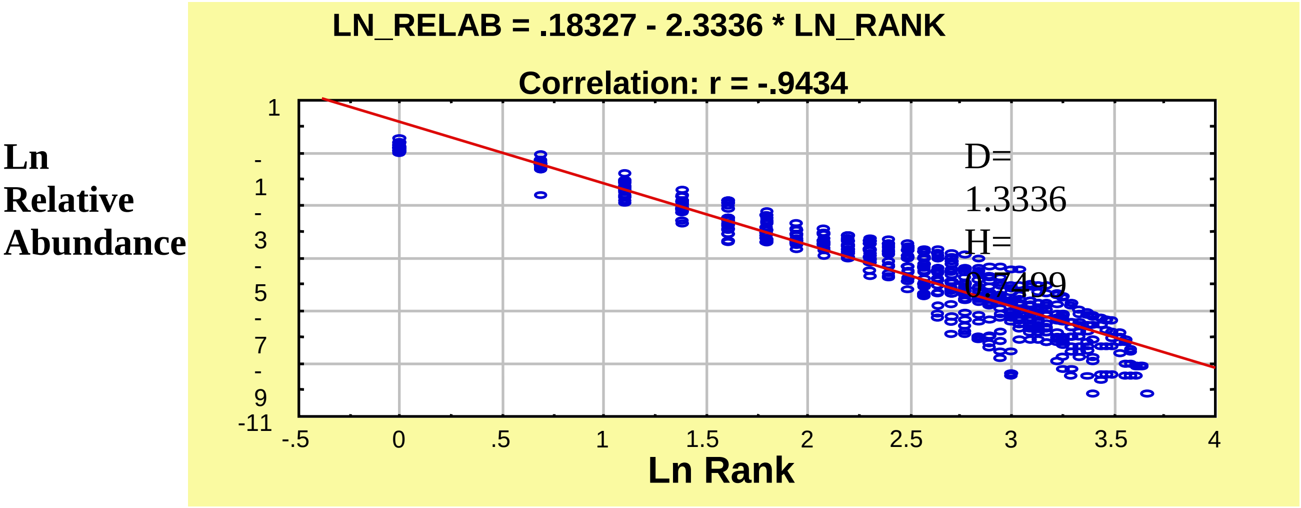
Long-term box turtle (*Terrapene ornata*) population studies in SEV grasslands have been continued from the 1980's, and have identified life history aspects and trends in population dynamics (Nieuwolt 1996, Nieuwolt-Dacanay 1997). Seasonal bird densities in desert, grassland and woodland habitats were collected 1991-1998, and show species-specific responses to climate-driven food resource availability (Friggens and Parmenter, in prep.). Large-scale bird distributional changes were related to land-use vegetation changes (Mehlman 1997). We are integrating our data with bird studies by the U.S.D.A. Forest Service.

SEV LTER studies of 10 yr of rodent and rabbit populations show significant linkages between abundances (**fig. I.5**), precipitation and vegetation dynamics (Ernest et al. 2000) with varying time lags of 2-12 months. Diets of 15 common rodents across six ecosystems were analyzed (Hope & Parmenter, submitted), along with rodent seed fungi (Herrera et al. 1997). Small mammal herbivory on *L. tridentata* was found to fluctuate with climate and herbivore density, causing morphological changes in *L. tridentata* (Ernest 1994). The El Niños of 1992 and 1998 resulted in pronounced increases in rodent densities, consistent with our "trophic cascade" hypothesis (increased NPP from wet El Niño winter-springs lead to lagged population growth by rodents). These studies helped explain the Hantavirus epidemic in 1993 (Parmenter et al. 1993, Parmenter and Vigil 1993, Parmenter 1995), and contributed to predictive models for bubonic plague (Parmenter et al. 1999, Enscore et al. submitted). Our methods for measuring rodents have been validated under field conditions (Parmenter et al. submitted), and have been adopted by the CDC world-wide (Parmenter et al. 1998, 1999, Mills et al. 1995). SEV data contributed to a 1998 public health warning on an incipient hantavirus outbreak, and a graduate student is now evaluating the public effectiveness of such warnings.

The coyote is a widespread omnivore on the SEV, and may provide "top down" controls on small mammal populations. Diet analyses showed a wide range of prey species, contributing to unusual stability in coyote densities (Hernandez et al. submitted).

A long-term exclosure study was initiated in 1995 to determine the effects of herbivorous and granivorous rodents and rabbits on plants, other animals and soils in grassland and *L. tridentata* shrublands on the SEV and Jornada LTER sites and at the Mapimi Biosphere Reserve, Mexico. To date, our field measurements on vegetation, soil surface disturbance, ants, grasshoppers, and termites have shown species-specific responses to herbivore and granivore removals based on ant/rodent seed preferences and soil disturbances by rodents (Data: http://sevilleta.unm.edu/research/local/planimal/smes/)

Grassland Ln Species Rank x Ln Relative Abundance



Larrea-Grassland Ln Species Rank x Ln Relative Abundance

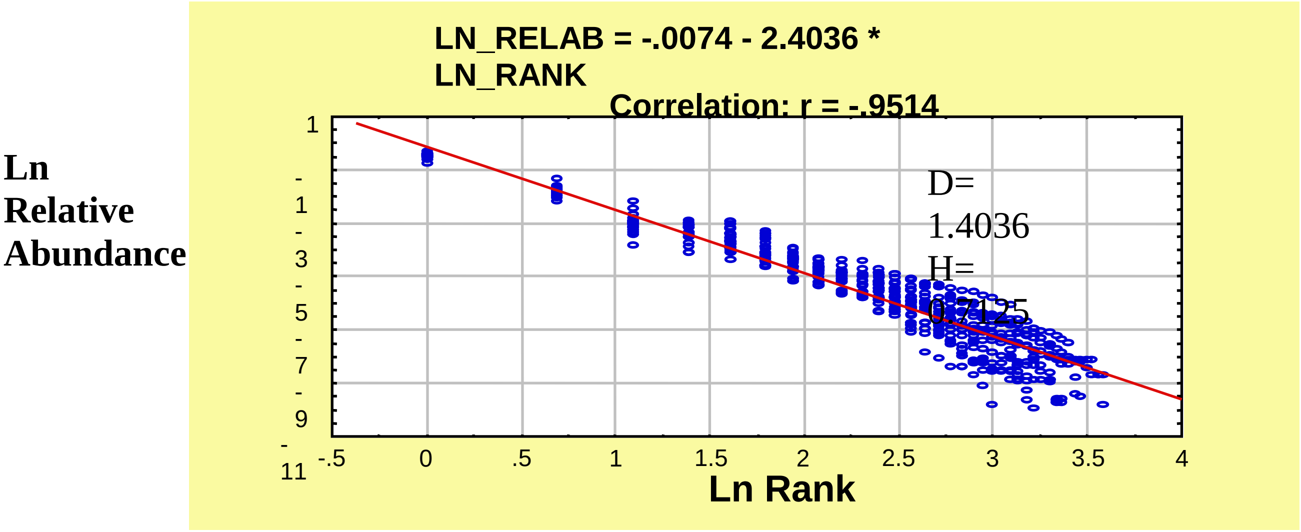


Figure I.4. Using species relative abundance-rank distributions (dominance-diversity curves), we studied relationships among dominant, subordinate and transient (rare) species on the line intercept transects for the grassland and creosote-grassland transitions. Fractal dimensions and Hurst exponents of species distributions indicate increasing fluctuations from creosote-grassland to grassland transitional zones, and suggest that species interactions are stronger at the grass dominated transect (D=1.3336 and H=0.7499), compared to creosote dominated one (D=1.4036 and H=0.7125. As expected, transient species are more variable than other species at both transects (Li et al. submitted). Other analyses from the line intercept studies are demonstrated in subsequent figures.

Dynamics of ecto- and endo-parasite communities were studied 1989-1998 among 25 rodent species, and identified patterns of parasite prevalence with host age, sex, mass, density, habitat, season, and precipitation. Parasite groups included fleas, ticks, bot flies, acanthocephalans, nematodes, cestodes and coccidia. Significant variables predicting parasite prevalence's for specific parasites included habitat/site, season, winter precipitation and host species (Duszynski et al. 1992, Wilber & Patrick 1997, Wilson et al. 1997, Decker 1999).

Ground-dwelling arthropod communities were sampled on the core sites from 1989-present, to determine differences in community structure among the SEV ecosystems, and how variation in seasonal and annual precipitation and vegetation influence populations of herbivores, predators and detritivores. Population data from over 800 taxa indicated close relationships of herbivores (primarily grasshoppers) with vegetation changes, as mediated by rainfall and summer temperatures, but highly stochastic relationships among predators and detritivores with habitat type and climate dynamics (Brantley 1997). Arthropod predators and detritivores demonstrated overlaps in species compositions with adjacent ecosystems, while herbivores exhibited closer associations with vegetation architecture and species composition.

I.2.F. Patterns and frequency of disturbances: Precipitation cycles, fires, and animal disturbances are the major disturbance types being investigated. **Drought cycles and ENSO signals** have been reconstructed for SEV from historic weather data, tree ring analyses and fossil packrat middens (Swetnam and Betancourt 1998), and vegetation responses (mortality, establishment, physiology, landscape distributions) have been determined for the dominant woody and herbaceous plant species (McGee & Marshall 1993, Shanley et al. 1998, Gill 1999, Pendall et al. 1999, Swetnam et al. 1999, Pendall 2000, Peters & Herrick in press). Climate impacts also influence small mammal body sizes (Smith et al. 1998). Plant population genetic patterns and dynamics from climate history have been described for *L. tridentata* (Duran et al. submitted) and an annual mustard, *Lesquerella fendleri* (Evans and Cabin 1995, Cabin et al. 1997a,b, Roll et al. 1997, Cabin et al. 1998, Mitchell 1997a,b, Mitchell & Marshall 1998). **Natural wildfires** are more prevalent in areas without livestock (like SEV), and we have examined responses of plants (Gosz & Gosz 1996, White et al. 1999, White & Loftin 2000, Parmenter & Lightfoot, submitted) and animals (Zimmer & Parmenter 1998, Parmenter et al. submitted). Fire data: http://sevilleta.unm.edu/data/archive/fire/. **Animal disturbances**, through herbivory, granivory and burrowing, cause spatial heterogeneity in faunal, floral and microbial patterns, particularly at transition boundaries (Kieft 1994, Hawkins 1996, Fields et al. 1999, Ayarbe & Kieft 2000). Experimental reintroduction of prairie dogs to SEV (Davidson et al. 1999) and natural reinvasions will continue to be studied in future work.

I.3. Model Development and Synthesis: We have used simulation modeling in three ways: 1) to generate hypotheses that can be tested using experiments; 2) to synthesize results from experiments and monitoring efforts with information in the literature to determine gaps in our knowledge and to identify key processes affecting transition dynamics; and 3) to make predictions as to the future location, composition, and dynamics of transitions.

The model SOLARFLUX was used to develop energy budgets for the entire SEV, based on elevation, slope, aspect, and latitude (SEV GIS/DEMs). Potential Evapotranspiration (PET) values for each 30x30 meter pixel (total of 2.76 million pixels) for different months were computed with average long-term precipitation data, and Leaf Area Indices (LAI) were estimated using the SEV vegetation map (**fig. I.6**). A preliminary analysis used spatially

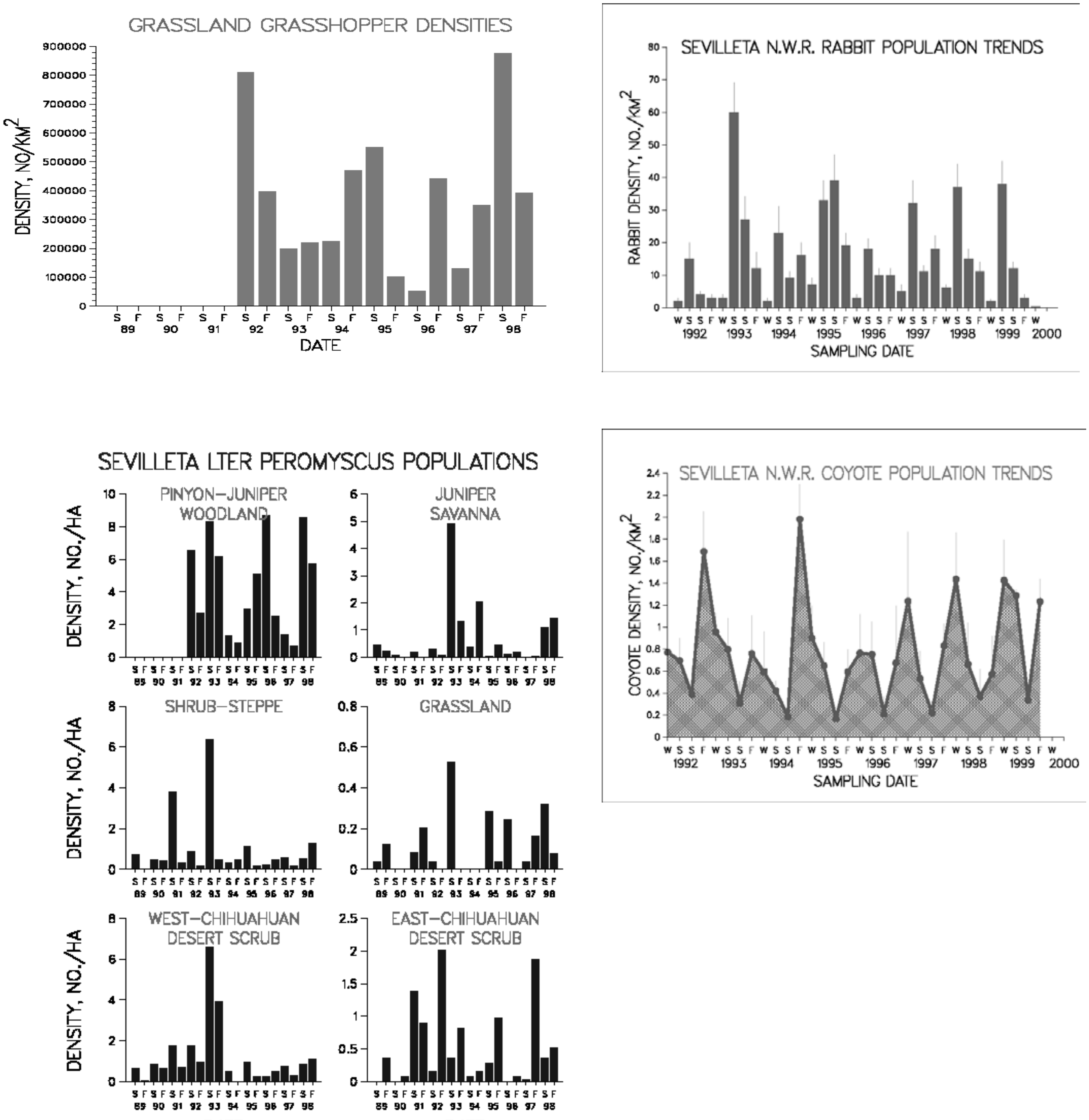


Figure I.5. Sevilleta studies of the dynamics of mammals and arthropods demonstrate the high variances that accompany high variability in precipitation and vegetation. Individual species population dynamics are even greater for some groups such as rodents.

distributed precipitation estimates, vegetation, soils, temperature, and solar radiation to model potential evapotranspiration, actual evapotranspiration, and water deficit. Analyses of the vegetation and LAI maps have provided evidence for nonequilibrial processes in the SEV (Milne 1998) and for exploring scaling issues related to new sensors such as MODIS (Milne & Cohen 1999, http://algodones.unm.edu/waterbal/waterbal.html).

The spatially explicit hydrologic model SPLASH (Simulator for Processes on Landscapes: Surface/subsurface Hydrology) has been calibrated for SEV, and was modified to better simulate arid land hydrology and run at a daily time step. SPLASH couples atmosphere, vegetation, and surface-subsurface hydrology in a spatially-explicit context, with time steps of 1 sec to 1 day (Data: http://sevilleta.unm.edu/research/local/water/splash/). The model allows simulation of high-frequency, but important, precipitation runoff events. SPLASH simulates lateral flows of water across the landscape, an important water redistribution mechanism during periods of heavy rainfall. SPLASH was shown to accurately simulate soil moisture when soil characteristics are accurately known, but the existing soils map is inadequate for accurate simulations across the SEV. A daily-time step version (SPLASH-DAY) has been implemented for the 1.08 million 30 m^2 cells that compose the SEV. SPLASH-DAY provides spatially-explicit estimates of soil moisture and evapotranspiration and can be used to estimate net primary productivity for comparison with other methods, such as MODIS (Milne & Cohen 1999).

Another approach to simulating vegetation dynamics is to use an individual plant-based simulation model (ECOTONE) developed to investigate transition zones between grass- and shrub-dominated ecosystems (Coffin 1997, 1998). Similar to gap dynamics models of forests (Shugart 1984), ECOTONE simulates the recruitment, growth, and mortality of each plant on a small plot at an annual time step (**fig. I.7**). Driving variables include climate, soil texture, and disturbance. To date, our modeling has focused on Shortgrass Steppe - Chihuahuan Desert transitions. The model simulates dominant species and 8-10 additional groups of species representing various life history traits (shrubs, annual and short-lived perennial C_3 and C_4 grasses and forbs). We incorporated a daily time step, multi-layer model of soil water (SOILWAT; Parton 1978) into ECOTONE to allow seasonal dynamics in soil water availability to affect and be affected by the vegetation. Daily information on soil water processes, including losses to interception, evaporation, and transpiration, as well as soil water content by depth are simulated in the SOILWAT module, and passed to the establishment and growth routines on a daily or monthly basis. Information on litter and aboveground and belowground production by depth are passed from the growth and mortality routines to the SOILWAT module. We used the ECOTONE model to synthesize data from the transition transects to determine if spatial and temporal differences in resource use could account for species coexistence patterns (Coffin 1997). Simulations using a GFDL climate change scenario (increased spring-summer precipitation and temperature) suggested a shift to dominance by *B. eriopoda* at all sites. We also conducted simulations both with and without feedbacks between vegetation and soil structure as simulated by the SOILDEV module. *B. eriopoda* response depended on initial soil properties and feedbacks between vegetation and soil structure**.** These results suggested that the most dynamic sites would occur at the transition between grasses and shrubs where organic matter inputs can modify the soil properties through time to increase plant available water and support grass establishment and growth. In contrast, sites with a very limited capacity to store water (very gravelly sandy loams) are expected to remain dominated by shrubs because of constraints on *B. gracilis* seedling establishment.

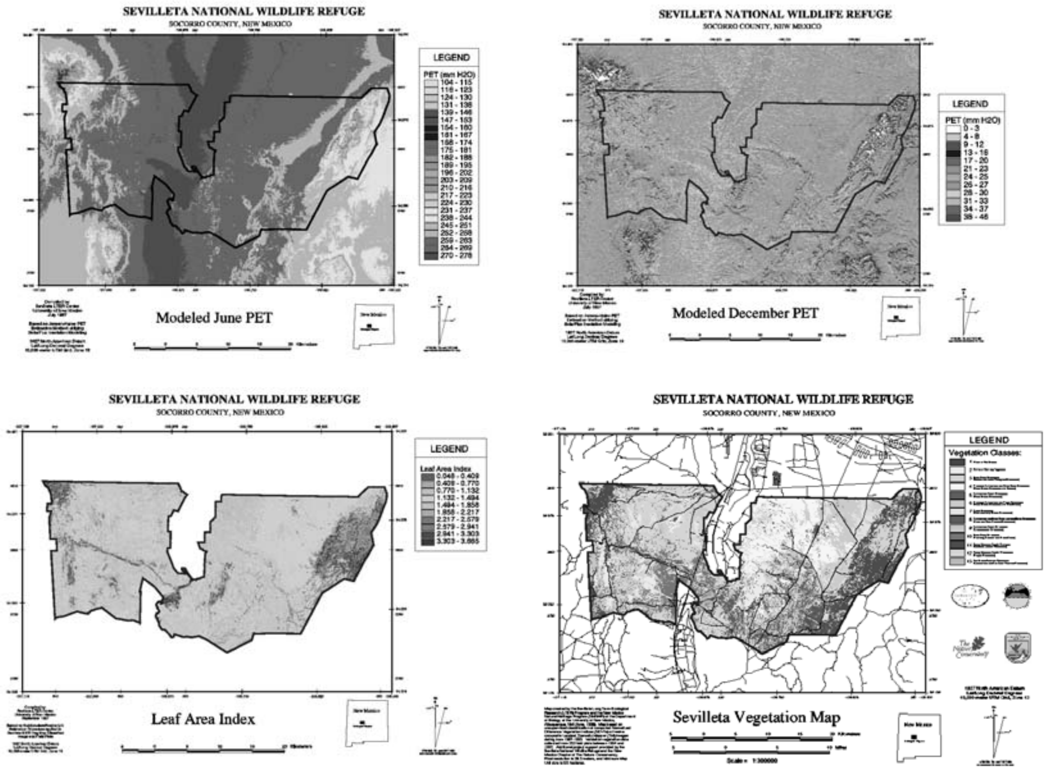


Figure I.6. (top) PET estimates for SEV based on the SOLARFLUX model using elevation, slope, aspect, and latitude. PET values were determined for each 30 m x 30 m pixel (total of 2.76 million pixels). June and December are shown for a contrast. (lower left) LAI estimates for SEV, (lower right) Vegetation Map for SEV based on remote imagery and ground validation.

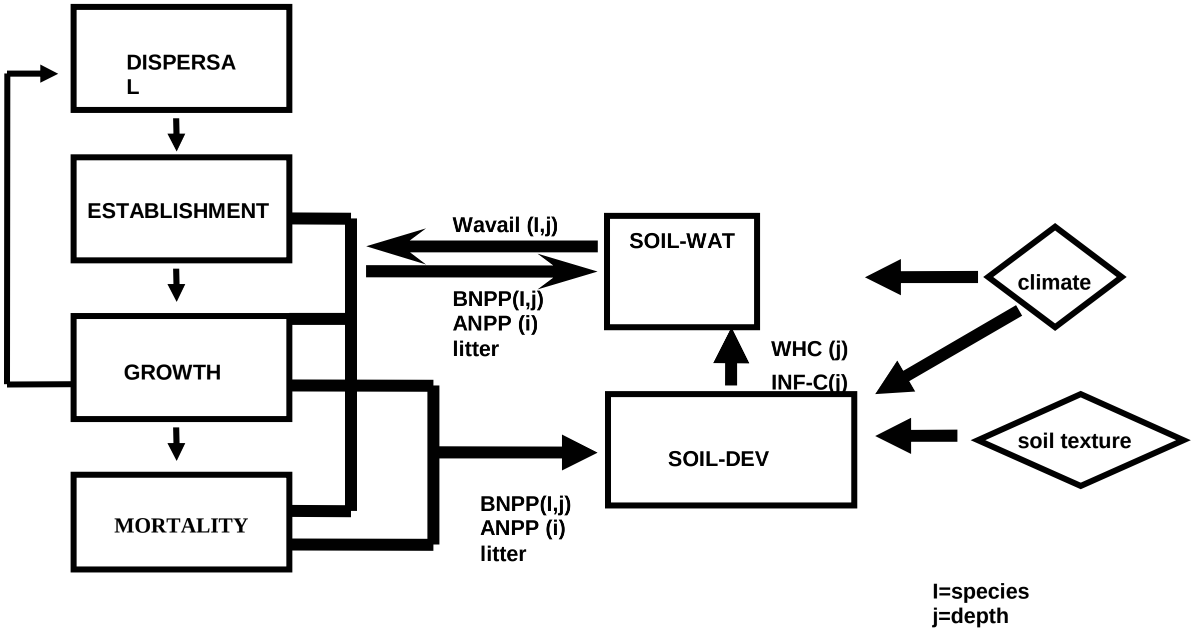


Figure I.7. Diagram of ECOTONE simulation model. AW is available water for plant growth, ANPP and BNPP are above- and below-ground net primary productivity, INF-C is soil water infiltration capacity and WHC is the plant available water holding capacity of the soil.

I.4. Sevilleta LTER Publication List, 1994-2000.

Journal articles: Total = 87

Andreas, Edgar L., Reginald J. Hill, James R. Gosz, Douglas I. Moore, William D. Otto, and Achanta D. Sarma. 1998. Stability dependence of the Eddy-accumulation coefficients for momentum and scalars. **Boundary-Layer Meteorology**, 86:409-420.

Andreas, Edgar L., Reginald J. Hill, James R. Gosz, Douglas I. Moore, William D. Otto, and Achanta D. Sarma. 1998. Statistics of surface-layer turbulence over terrain with meter-scale heterogeneity. **Boundary-Layer Meteorology**, 86:379-408.

Ashby, Patricia D. 1997. Conservation of mass-specific metabolic rate among high- and low-elevation populations of the acridid grasshopper, *Xanthippus corallipes*. **Physiological Zoology**, 70:701-711.

Ayarbe, J. P., and T. L. Kieft. 2000. Mammal mounds stimulate microbial activities in a semiarid shrubland. **Ecology**, In press.

Brookhart, J.O. and S.L. Brantley. Solpugids (Arachnida) of the Sevilleta NWR, New Mexico: species richness and abundance 1989-1995. **Southwestern Naturalist**. In press.

Brown, James H., David W. Mehlman, and George C. Stevens. 1995. Spatial variation in abundance. **Ecology**, 76:2028-2043.

Cabin, Robert J., Ann S. Evans, and Randall J. Mitchell. 1997. Do plants derived from seeds that readily germinate differ from plants derived from seeds that require forcing to germinate? A case study of the desert mustard *Lesquerella fendleri*. **The American Midland Naturalist**, 138:121-133.

Cabin, Robert J., Ann S. Evans, and Randall J. Mitchell. 1997. Genetic effects of germination timing and environment: An experimental investigation. **Evolution,** 51:1427-1434.

Cabin, Robert J., Randall J. Mitchell, Diane L. Marshall. 1998. Do surface plant and soil seed bank populations differ genetically? A multipopulation study of the desert mustard *Lesquerella fendleri* (Brassicaceae). **American Journal of Botany**, 85:1098-1109.

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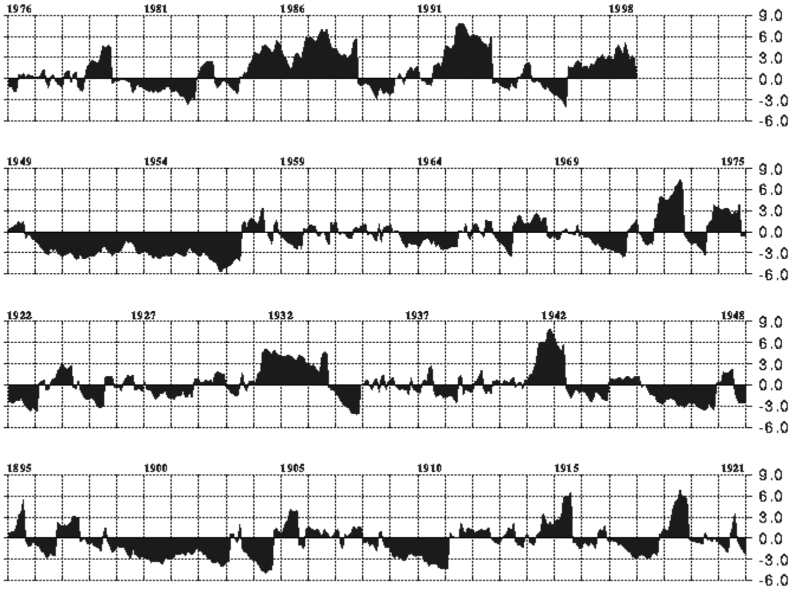
Creosote Invasion of Grassland
Sevilleta LTER, NM

1915

1989

Paired photos show extensive invasion of a grassland habitat by *Larrea tridentata*, a Chihuahuan Desert shrub. The major invasion occurred in the 1950's.

Palmer Drought Severity Index



New Mexico - Division 05: 1895-1998 (Monthly Averages)

The Palmer Drought Index for central New Mexico demonstrates two significant climate patterns in the current century: prolonged drought from 1942-57 and a prolonged wet period through the 1980's and early 1990's. These decade-scale periods were significant in causing range expansion or contraction of C_3 woody species. The drought resulted in Desert shrubs invading perennial grasslands but loss of Juniper and Piñon Pine at lower elevations. The wet period allowed expansion of Juniper and Piñon to lower elevations but did not result in contraction of desert shrubs.

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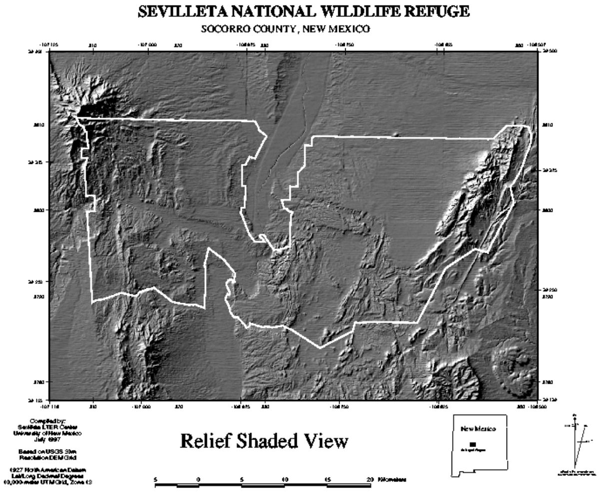

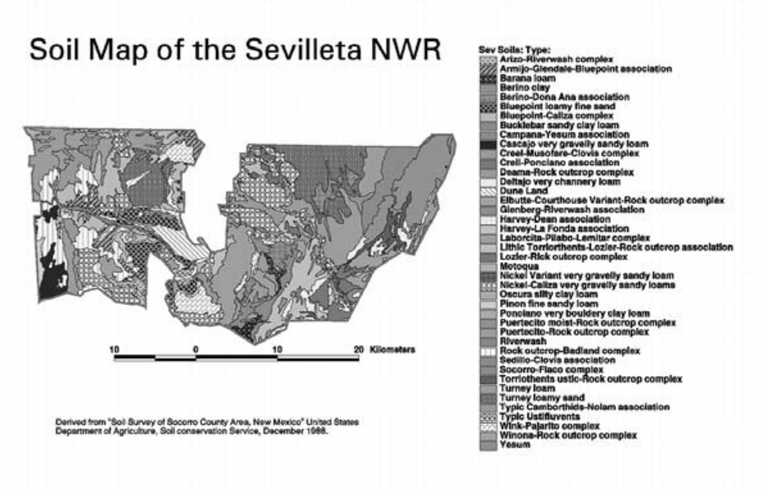

The topography of the region (Rio Grande Valley) shown at the left and of the Sevilleta (upper right) are important factors in the current location of the biome transitions that occur in central New Mexico. Topography controls air masses, storm tracks (via jet streams) and the movements of flora and fauna in the region. Topography also controls human activities (land use). The flood plain of the Rio Grande is heavily used for ranching, agriculture and urban development. The Sevilleta boundary, separating grazed from ungrazed conditions, is clearly seen from space. The mountains also constrain air mass movements and their chemical loads. Increased N deposition occurs principally along the east side of the Sevilleta because of the mountain barriers to movement east. The soils of the Sevilleta further affect the patterns/processes of biota.

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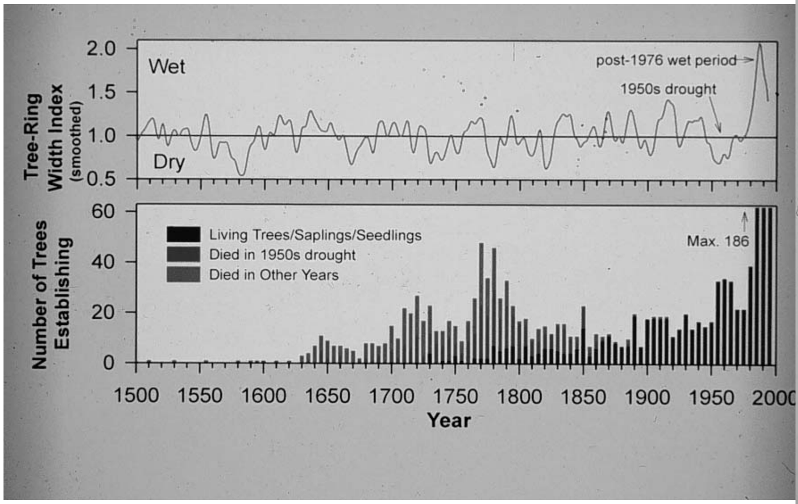

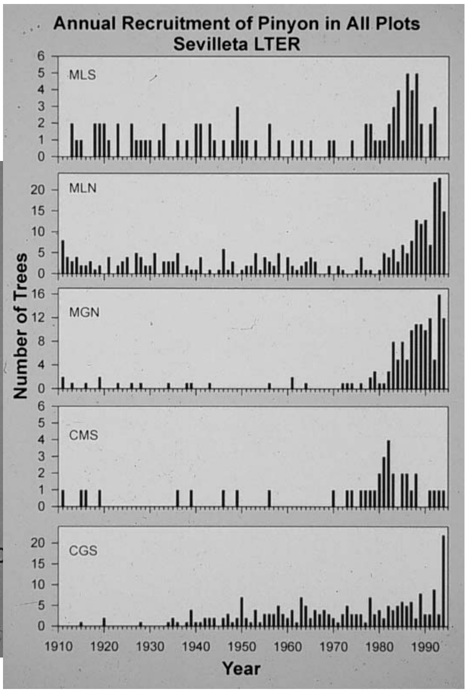

A few thousand Piñon trees have been tagged, measured, cross-dated to age of establishment and mortality at Sevilleta, and compared with regional climate reconstructions from tree rings. Broad-scale mortality occurred during catastrophic droughts, such as 1575-1595, 1667-1680, 1730-1750, 1890-1904, and 1942-1957. There was an unprecedented wet period in the 1980's-90's. The drought caused significant mortality of Juniper and Piñon at lower elevations and invasion of *Larrea* into former grasslands and lower Juniper savanna (upper right photo). The more recent wet interval allowed extensive Juniper and Piñon recruitment into areas of past tree mortality and grassland habitats where they had not been in the decades of this century before the 1950's drought (upper left photo). Piñon recruitment occurred throughout the Sevilleta and the region (lower right figure).

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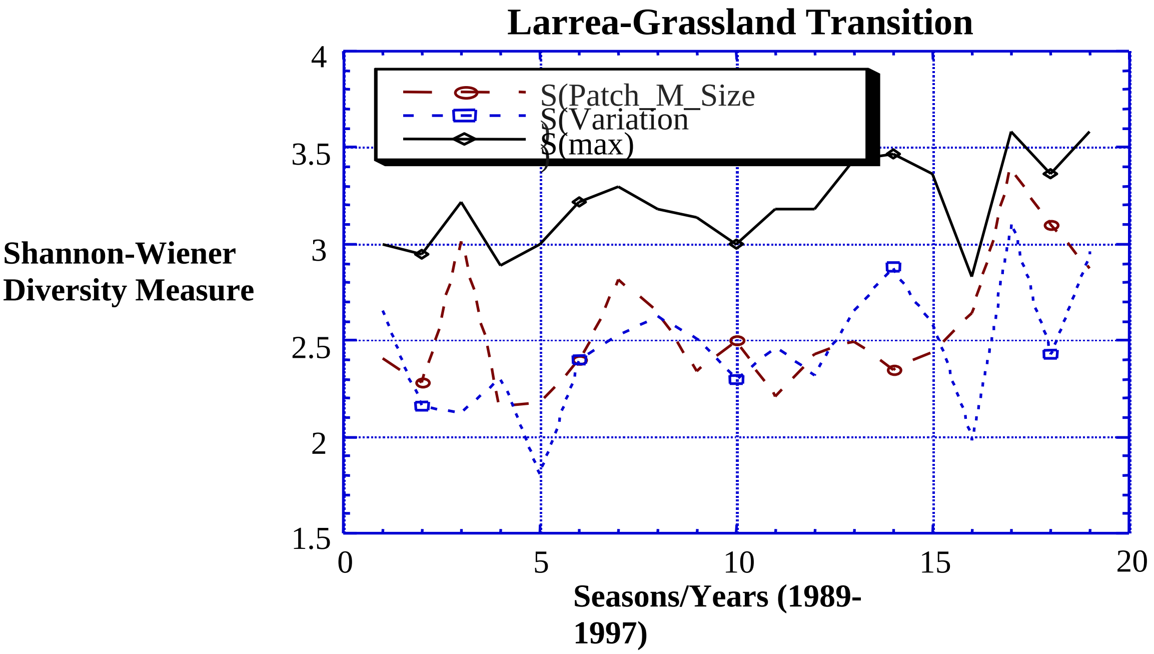

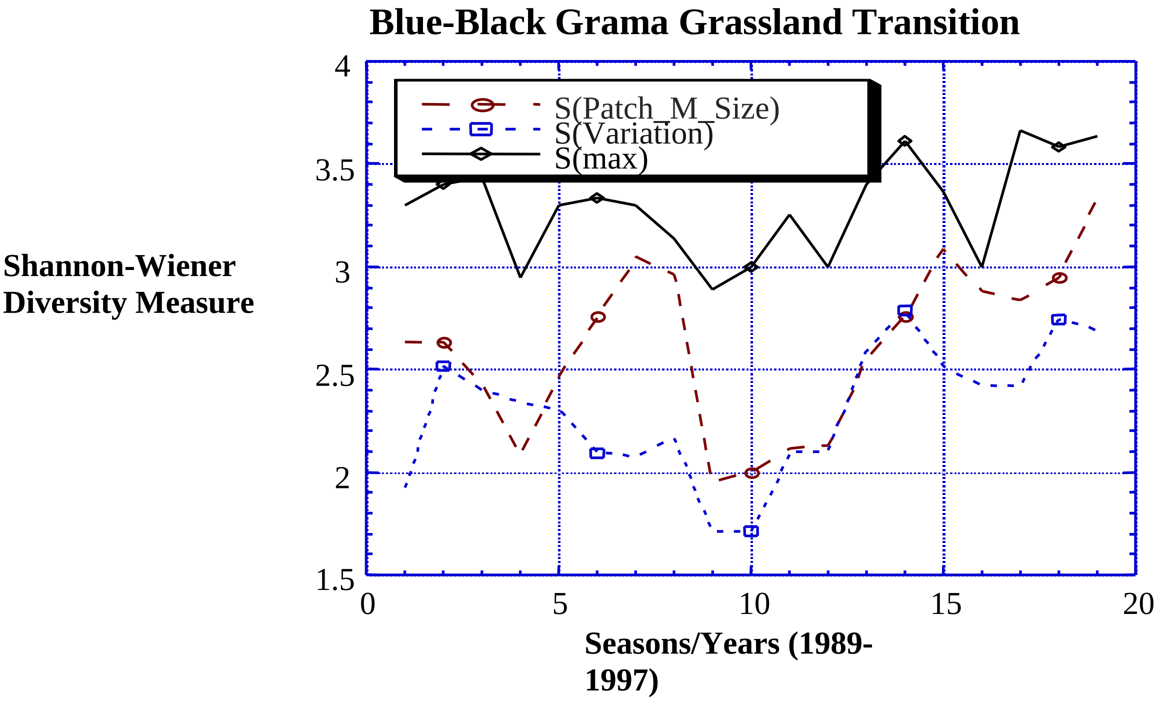

Using Shannon-Wiener Diversity Measures based on mean patch sizes and variations for each species, we calculated changes in species diversity over time on the line intercept transects. Here we showed that the trends of these measures in both Grassland and *Larrea*-Grassland transitions are increasing with the higher precipitation in the recent years (Li et al. submitted).

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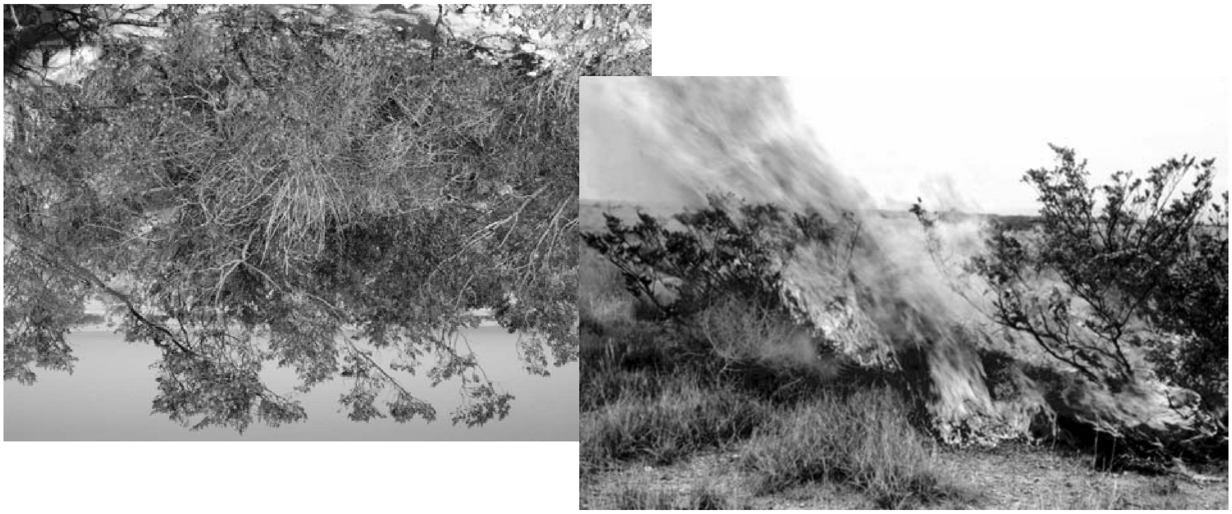

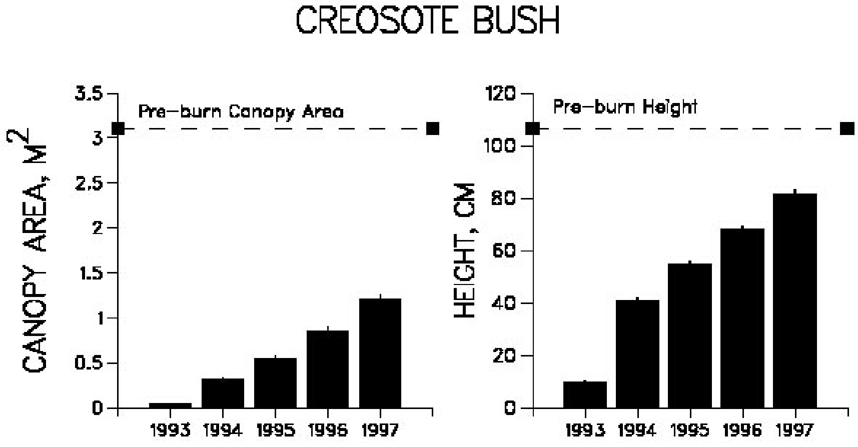

Larrea can occur in relatively dense stands with little ground cover. In such situations fire would be ineffective causing mortality of *Larrea* adults. An interaction with an exotic; however, could provide a different result. Tumbleweed (*Salsola kali*) moves long distances over the landscape after senescence and is trapped by the shrub architecture. Fire in this situation may have sufficient fuel to create the hot fire necessary to cause shrub mortality. Experimental fires on Creosote Bush (*Larrea*) resulted in mortality of mostly smaller individuals and resprouting of larger individuals. The figure above demonstrates the recovery of these resprouting individuals following the fire in 1992 relative to their preburn conditions.

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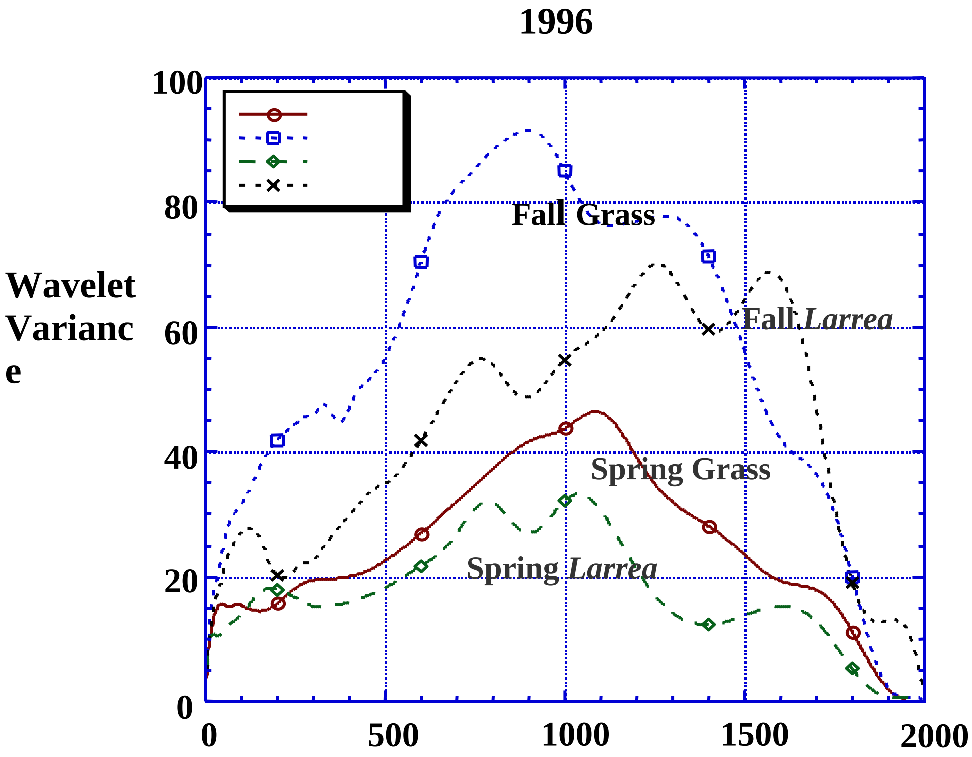

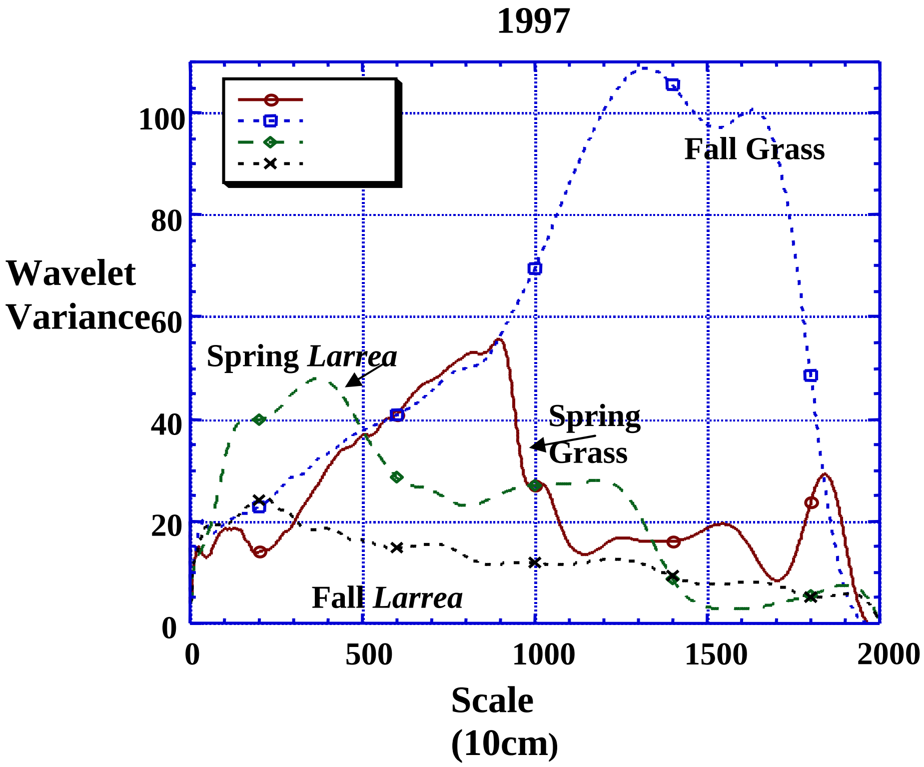

Wavelet analysis is the relatively new mathematical tool for identifying cross-scale dynamics and dominant scale(s) of the line intercept plant transects. Results here further support large scale dynamics and scale shifts in patterns for grassland and Larrea-grassland transitions during the spring and fall of 1996 and 1997 (Li et al., submitted).

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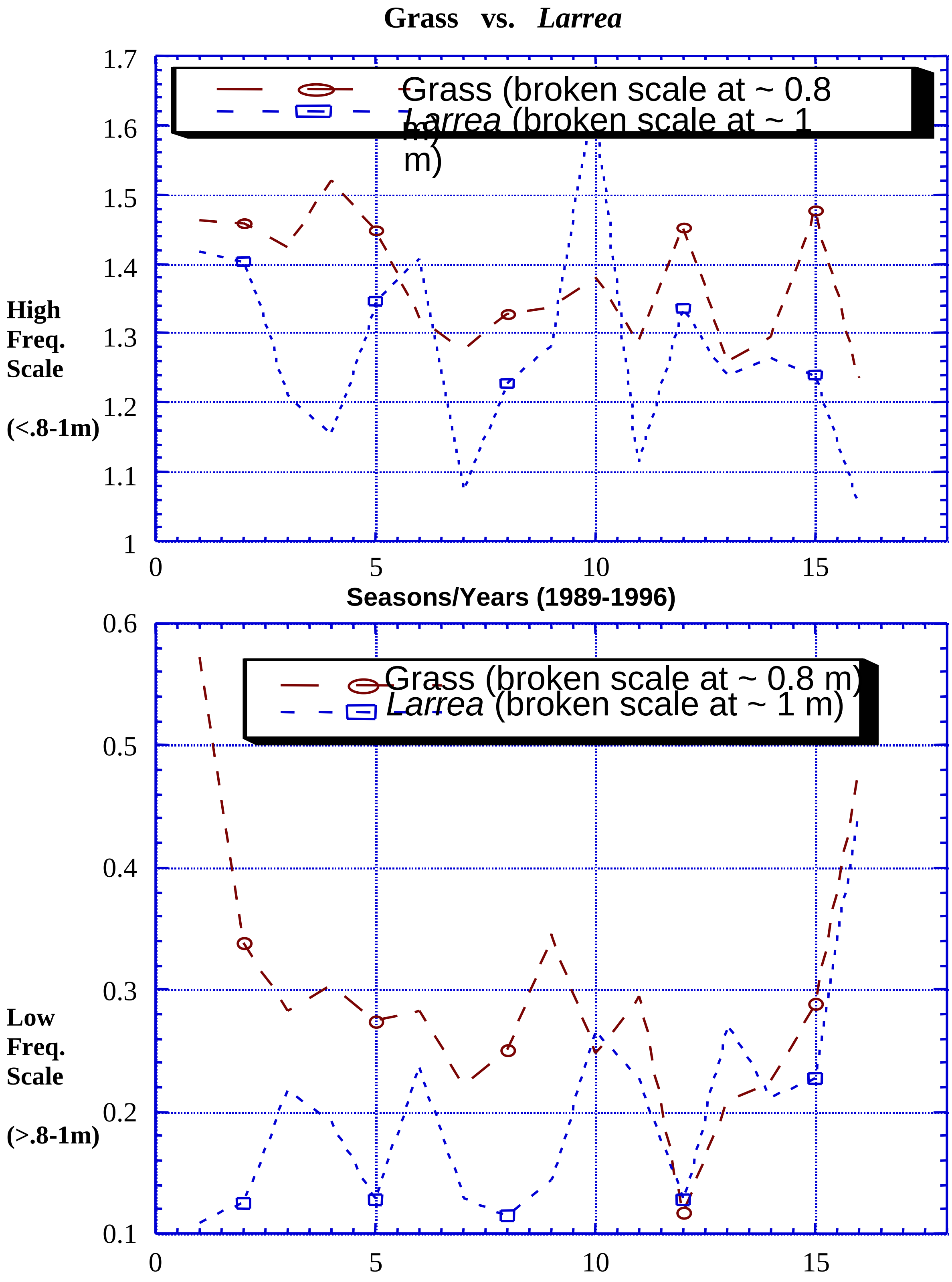
Advisor: Dr. Bruce Harrison, New Mexico Institute of Mining and Technology.



Analyses of the vegetation line intercept data demonstrates a scale break between 0.8 and 1.0 m for the herbaceous vegetation in both the *Larrea*-grassland, and Blue-Black Grama grassland. Below this scale break (i.e., high frequency) are simple fractals and above the scale break (i.e., low frequency) are multifractals implying multifactor controls (Over and Li submitted).

Charles Buxbaum , Ph.D. 2000. Geomorphology, soil development, distribution of desert and prairie plant populations at the Chihuahuan Desert/Shortgrass Prairie ecotone; and the responses of soils and desert and prairie grama grasses to acute changes in moisture availability.
Advisors: Dr. James Gosz and Dr. Cliff Dahm, University of New Mexico.

Tad Crocker, Ph.D. 1996. Climatic and geomorphic controls on semiarid fluvial ecosystems.
Advisor: Dr. Clifford Dahm and Dr. Manuel Molles, University of New Mexico.

S. Morgan Earnest. Ph.D. 2000. Rodents, plants and precipitation: Spatial and temporal dynamics of consumers and resources.
Advisor: Dr. James Brown, University of New Mexico.

Greg Farley, Ph.D. 1995. Thermal and social consequences of obligate cavity roosting in *Campylorhynchus* wrens.
Advisor: Dr. J. David Ligon, University of New Mexico.

Joslyn M. Garcia. M.S. 2000. Prehistoric and historic ecosystem management of the Sevilleta National Wildlife Refuge.
Advisor: Dr. James R. Gosz.

Kim Decker, M.S. 1999. Endoparasitic infection of Dipodomys and Perognathus species on the Sevilleta National Wildlife Refuge, 1989-1998.
Advisor: Dr. Don Duszynski, University of New Mexico.

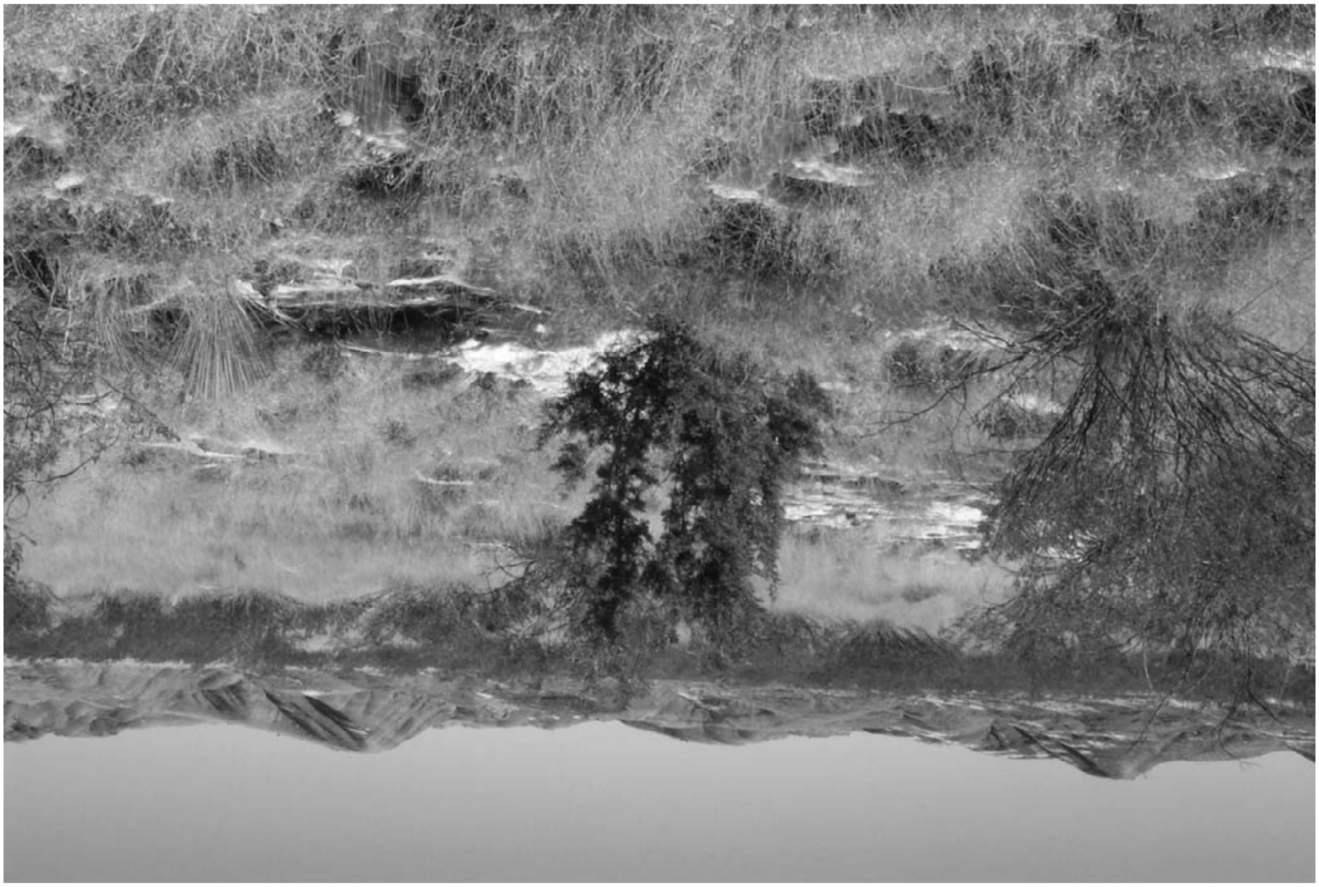
Jesse Hamilton, M.S. 1998. The spatial distribution of rodent activity: resource removal in grassland and shrubland habitats in the Chihuahuan Desert.
Advisor: Dr. James Brown, University of New Mexico.

John Hnida, Ph.D. 1998. Clarifying the taxonomy and systematic of *Emieria* of murid rodents with cross-transmission experiment, ITSI sequencing and reboprinting.
Advisor: Dr. Donald Duszynski, University of New Mexico.

Tamara Hochstrasser. Ph.D. 2000. The relationship between soil water dynamics and vegetation patterns at multiple scales in a grassland-shrubland ecotone.
Advisor: Dr. Deb Peters, New Mexico State University (formerly at CSU).

Kim L. Hunter, Ph.D. 1996. Molecular systematics of the genus *Larrea* (University of Nevada)
Advisor: Dr. Brett Riddle, University of Nevada, and Dr. Julio Betancourt, USGS.

Joshua Leffler, Ph.D. 1999. Temporal and geographic physiological variation in Fremont Cottonwood.
Advisor: Dr. Ann Evans, University of New Mexico.



The proximity of different life forms from adjacent biomes creates opportunities for unusual assemblages of species. Here are representatives from Juniper savanna (*Juniperus*), Chihuahuan Desert (*Larrea*, *Bouteloua eriopoda*), Shortgrass Steppe (*Yucca glauca*). Not apparent, but present, are other Shortgrass Steppe and desert species.

Sam Loftin, Ph.D. 1994. Sewage sludge application to semiarid grassland: effects on soil vegetation and surface hydrology.
Advisor: Dr. James R. Gosz, University of New Mexico.

David Mehlman, Ph.D. 1995. The spatial distribution of abundance: analysis of the geographic range.
Advisor: Dr. James Brown, University of New Mexico.

Tamera J. Minnick, Ph.D. 1998. Abiotic factors affecting distribution and dominance patterns of two C4 perennial grass species. Colorado State University.
Advisor: Dr. Deb Peters, New Mexico State University (formerly at CSU).

Maria Nieuwolt, Ph.D. 1993. The ecology of movement and reproduction in the western box turtle in central New Mexico.
Advisor: Dr. Astrid Kodric-Brown, University of New Mexico.

Michael Patrick, Ph.D. 1994. Parasites of *Dipodomys merriami*: patterns and processes.
Advisor: Dr. Donald W. Duszynski, University of New Mexico.

Elise Pendall, Ph.D. 1997. Precipitation seasonality recorded in D/H ratios of pinyon pine cellulose in the southwestern United States.
Advisor: Dr. Julio Betancourt and Dr. Steven Leavitt, USGS & University of Arizona.

P. K. Van de Water, Ph.D. 1999. Carbon isotopic and stomatal density variations in modern and fossil leaves of key plants in the western United States.
Advisor: Dr. Julio Betancourt and Dr. Steven Leavitt, USGS & University of Arizona.

Other Publications: Total = 18

Aguilar, Richard, Samuel R. Loftin, Tim J. Ward, Kenny A. Stevens, and James R. Gosz. 1994. Sewage Sludge Application in Semiarid Grasslands: Effects on Vegetation and Water Quality. *WRRI Report No. 285.* New Mexico Water Resources Research Institute, NMSU, Las Cruces. Pp. 1-75.

Brunt, James W. 1994. Research Data Management in Ecology: A Practical Approach for Long-Term Projects. Pages 272-275, *In:* J.C. French and H. Hinterberger (eds.). *Proceedings of the Seventh International Working Conference on Scientific and Statistical Database Management.* IEEE Computer Society Press.

Dahm, Clifford N., and Douglas I. Moore. 1994. The El Nino/Southern Oscillation phenomenon and the Sevilleta Long-Term Ecological Research Site. Pages 12-20, *In: El Nino and Long-Term Ecological Research (LTER) Sites.* LTER Network Climate Committee.

Frey, Timothy C., and Charles G. Curtin. 1997. A low-tech technique for aerial photograph analysis. *Bulletin of the Ecological Society of America,* 78:203-204.

A commercial-scale lathe house at the Sevilleta Field Station is used to germinate seeds from soil samples, test effects of microbiotic crusts on germination and N-fixation, and, in general, used to modify environmental conditions to allow studies of plant processes. A common garden area is immediately to the left of the lathe house in this figure for phenotypic studies of species.

Juniper (*Juniperus monosperma*) damage by the insect cambium borers (*Styloxus bicolor*) associated with winter drought. This “red flagging” begins to occur after 2 years of drought. These activities result in significant increases in litterfall that enhances the organic matter “footprint” in the understory of juniper individuals.

Lightfoot, D. C. 1997. The fauna of El Malpais National Monument. In: K. Mabery, editor. Natural history of El Malpais National Monument. *New Mexico Bureau of Mines and Mineral Resources, Bulletin* 156:139-154.

Lightfoot, D. C. 1996. A comparison of ground-dwelling arthropod assemblages among different habitats resulting from the 1977 La Mesa fire. Pages 166-178. In: Craig Allen, editor, Fire effects in Southwestern forests. Proceedings of the Second La Mesa Fire Symposium. *USDA Forest Service, General Technical Report RM-GTR*-286.

Loftin, Samuel R., Richard Aguilar, and Gale L. Wolters. 1995. Distribution of Soil TOC, TKN, and TP across a Chihuahuan Desert scrub/desert grassland ecotone. Pages 323-324, *In*: N.E. West (ed.). *Fifth International Rangeland Congress Symposium Proceedings*. International Rangeland Congress, Salt Lake City.

Loftin, Samuel R., and Carleton S. White. 1996. Potential nitrogen contribution of soil cryptogams to post-disturbance forest ecosystems in Bandelier National Monument, NM. Pages 140-148, *In:* Craig D. Allen (ed.). *Fire Effects in Southwestern Forests: Proceedings of the Second La Mesa Fire Symposium*. General Technical Report RM-GTR-286. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Michener, William K., James W. Brunt, and William H. Jefferson. 1995. New techniques for monitoring American Oyster (*Crassostrea virginica*) recruitment in the intertidal zone. *ICES Marine Sciences Symposium*, 199:267-273.

Otto, William D., Reginald J. Hill, Achanta D. Sarma, James D. Wilson, Edgar L. Andreas, James R. Gosz, and Douglas I. Moore. In Press. Results of the Millimeter-Wave Instrument Operated at Sevilleta, New Mexico. NOAA Technical Memorandum. Environmental Research Laboratories, U.S. Department of Commerce.

Otto, William D., Reginald J. Hill, James J. Wilson, James R. Gosz, and Douglas I. Moore. In Press. Results from optical scintillometers operated at Sevilleta, New Mexico. NOAA Technical Memorandum. Environmental Research Laboratories, U.S. Department of Commerce.

Parmenter, Robert R. 1995. Pecos National Historical Park mammal survey data help solve Hantavirus mystery. **Park Science**, 1995:12-13.

Parmenter, Robert R. 1999. Sevilleta Long-Term Ecological Research Program: Measuring Ecosystem Responses to Environmental Change. Pages 164-169, *In:* Deborah M. Finch, J.C. Whitney, J.F. Kelly, S.R. Loftin (eds.). *Rio Grande Ecosystems: Linking Land, Water, and People. Toward a Sustainable Future for the Middle Rio Grande Basin*. USDA Forest Service, Rocky Mountain Research Station.

Sarma, Achanta D., and Reginald J. Hill. 1996. A Millimeter Wave Scintillometer for flux measurements. NOAA Technical Memorandum ERL ETL-259. Environmental Technology Laboratory, U.S. Department of Commerce.

Research Experiences for Undergraduate (REU) students is an important effort that not only creates an educational opportunity for the students but generates important data for the LTER program. In turn these undergraduate students teach precollege students (lower photo).

Stafford, S.G., J.W. Brunt, and B.J. Benson. 1996. Training Environmental Information Managers of the Future. Pages 111-116, *In*: *Proceedings of Eco-Informa '96*, Lake Buena Vista, Florida, 4-7 November 1996. ERIM, Ann Arbor.

Stuever, Mary C., Clifford S. Crawford, Manuel C. Molles, Carleton S. White, and Esteban Muldavin. 1997. Initial Assessment of the Role of Fire in the Middle Rio Grande Bosque. Pages 275-283, *In*: Jason M. Greenlee (ed.). *Proceedings: First Conference on Fire Effects on Rare and Endangered Species and Habitats.* International Association of Wildland Fire, Fairfield, Washington.

White, Carleton S. 1996. The Effects of Fire on Nitrogen Cycling Processes within Bandelier National Monument, NM. Pages 123-139, *In:* Craig D. Allen (ed.). *Fire Effects in Southwestern Forests: Proceedings of the Second La Mesa Fire Symposium.* General Technical Report RM-GTR-286. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

White, Carleton S., David R. Dreesen, and Samuel R. Loftin. 1998. Cobble Mulch: An Anasazi Water-Conservation Gardening Technique. Pages 109-121, *In*: C.T. Ortega Klett (ed.). *Proceedings: 42nd Annual New Mexico Water Conference, Water Issues of Eastern New Mexico*. Tucumcari NM, October 2-3, 1997. New Mexico Water Resources Research Institute, NMSU, Las Cruces.

White, Carleton S., Samuel R. Loftin, Steven C. Hofstad. 1999. Response of Vegetation, Soil Nitrogen, and Sediment Transport to a Prescribed Fire in Semiarid Grasslands. Pages 83-92, *In:* Deborah M. Finch, J.C. Whitney, J.F. Kelly, S.R. Loftin (eds.). *Rio Grande Ecosystems: Linking Land, Water, and People. Toward a sustainable future for the Middle Rio Grande Basin.* USDA Forest Service, Rocky Mountain Research Station.

Wolters, Gale L., Samuel R. Loftin, and Richard Aguilar. 1995. Changes in Species Composition Along a Chihuahuan Desert Scrub/Desert Grassland Transition Zone in Central New Mexico. Pages 614-615, *In:* N.E. West (ed.). Fifth International Rangeland Congress Symposium Proceedings. International Rangeland Congress, Salt Lake City.

Yates, Terry L. 1995. Assessing and monitoring biological diversity at the genetic level. Pages 41-49, *In*: M.M. Watanabe and M. Yasuno (eds.). *Proceedings of the International Workshop on Biodiversity.* National Institute for Environmental Studies, Tsukuba, Japan.

Manuscripts Submitted:

Anand, M. and B. L. Li. Organization of plant communities in a transition zone: I. Spatiotemporal niche partitioning. Submitted to: Ecology.

Allen, A, B. L. Li, and E. L. Charnov. Population fluctuations, power laws, and mixture of lognormal distributions. Submitted to: Nature.

Highschool students regularly measure leaf litter and groundwater levels in the Rio Grande bosque near Albuquerque as a part of the Sevilleta Schoolyard LTER program. The data are added to a much larger set that documents changes in the riparian ecosystem.

Berckman, S. K. and D. C. Lightfoot.. Harvester ant (*Pogonomyrmex*) next distribution and microhabitat characteristics across the Chihuahuan Desert. Submitted to: Southwestern Naturalist.

Crocker, M.T., C. Dahm, D. Moore, M. Molles. A thunderstorm and ephemeral stream spate in a Juniper Woodland. Submitted to: J. of Arid Envir.

Crocker, M.T., M. Murillo, C. Dahm, M. Molles, D. Moore. El Nino/Southern Oscillation and the Rio Puerco Basin, New Mexico: precipitation, discharge, and suspended sediment load. Submitted to :Hydrologic Processes.

Duran, K., T. K. Lowrey, R. Parmenter, and P. Lewis. Genetic Diversity in diploid Larrea tridentata in the Chihuahuan Desert. Submitted to: Evolution.

Enscore, R. E., B. J. Biggerstaff, T. L. Brown, R. F. Fulgham, P. J. Reynolds, D. M. Engelthaler, C. E. Levy, R. R. Parmenter, J. A. Montenieri, J. E. Cheek, R. K. Grinnell, P. J. Ettestad, and K. L. Gage. Modeling relationships between climate and the frequency of human plague cases in the Southwestern United States, 1960-1997. Submitted to :Journal of Epidemiology.

Fuller, M. and B. L. Li. Dynamic diversity indices: measuring the effect of temporal and spatial heterogeneity on total diversity. Submitted to: Ecology.

Hope, A., and R. R. Parmenter. A comparison of rodent diets in multiple ecosystems in central New Mexico. Submitted to: The Southwestern Naturalist.

Hernandez, L., R. R. Parmenter, D. L. Lightfoot and J. DeWitt. Coyote population dynamics and diet diversity: Relationships among prey abundances, predator selectivity, and population stability. Submitted to: Ecology.

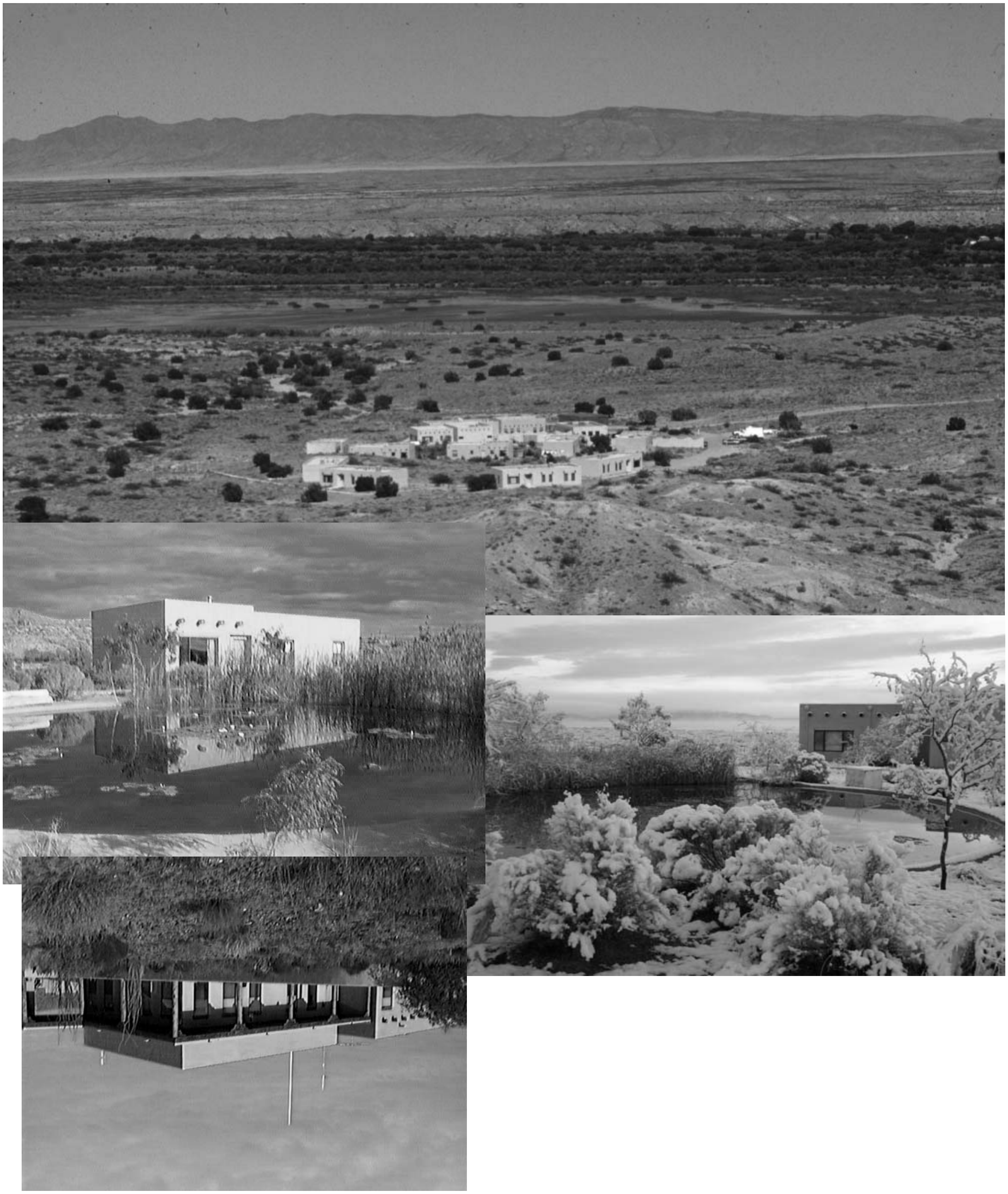
Huenneke,L. F., D. Clason, and E. Muldavin. Assessing spatial patterns of aboveground net primary production: a new method applicable to semi-arid ecosystems. Submitted to: J. of Arid Envir.

Kolasa, J, and B. L. Li, The balance of nature promotes diversity but habitat hierarchy may set limits. Submitted to: Nature.

Li, B. L., J. R. Gosz, A. Yuen, X. Wang, and G. Li. Ecotonal response to rapid climate change: Sevilleta vegetation transect data analyses. Submitted to: Proc. Nat. Academy of Sci.

Li, B. L., Why is the holistic approach becoming so important in landscape ecology? Submitted to: Landscape and Urban Planning.

Li, B. L. Tree-grass dynamics and ecological phase transitions in a North American subtropical *Prosopis* savanna parkland. Submitted to: Community Ecology.



The Sevilleta Field Station is located within the Sevilleta National Wildlife Refuge but operated by the University of New Mexico. Eight, 3-bedroom fully equipped houses allow sleeping for 48. A conference room, computer lab and miscellaneous other labs are available to scientists and students.

Muldavin, E.H., P. Neville and G. Harper. Remote-sensing-derived indices of grassland biodiversity in the Chihhuahuan Desert Ecoregion, U.S and Mexico: A comparative study of two grassland sites. Submitted to: Conservation Biology.

Muldavin, E.H., V. Archer, Y Chauvin, and E. Milford. Fire affects and vegetation response in lower montane conifer forests and woodlands of an isolated mountain range in southern New Mexico, USA. Submitted to: Vegetation Science.

Parmenter, R. R., and D. C. Lightfoot. Rodent community responses to fire in a desert grassland in New Mexico. Submitted to: Journal of Arid Environments.

Parmenter, R. R., and D. C. Lightfoot. Plant demographic responses to fire in a desert grassland ecosystem: Survivorship, regrowth, reproduction and herbivory. Submitted to: American Journal of Botany.

Parmenter, R. R., T. L. Yates, D. R. Anderson, K. P. Burnham, J. L. Dunnum, A. Franklin, M. T. Friggens, B. Lubow, M. Miller, G. S. Olson, C. A. Parmenter, J. Pollard, E. Rexstad, T. Shenk, T. R. Stanley, and G. C. White. Small mammal density estimation: A field comparison of grid-based versus web-based density estimators using enclosed rodent populations. Submitted to: Ecology.

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

Peters, D. P. C. Key processes limiting recruitment for two dominant grasses at a semiarid-arid grassland ecotone. Submitted to: Journal of Ecology.

Peters, D. P. C. Climatic variation and simulated patterns in seedling establishment of two dominant grasses at their ecotone. Submitted to: Journal of Vegetation Science.

Over, T. and B. L. Li, Scale shifts in semi-arid biome transitional zones. Submitted to: Nature.

Ryerson, D. E., and R. R. Parmenter. Vegetation change following removal of keystone herbivores from desert grasslands in New Mexico, USA. Submitted to: Journal of Vegetation Science.

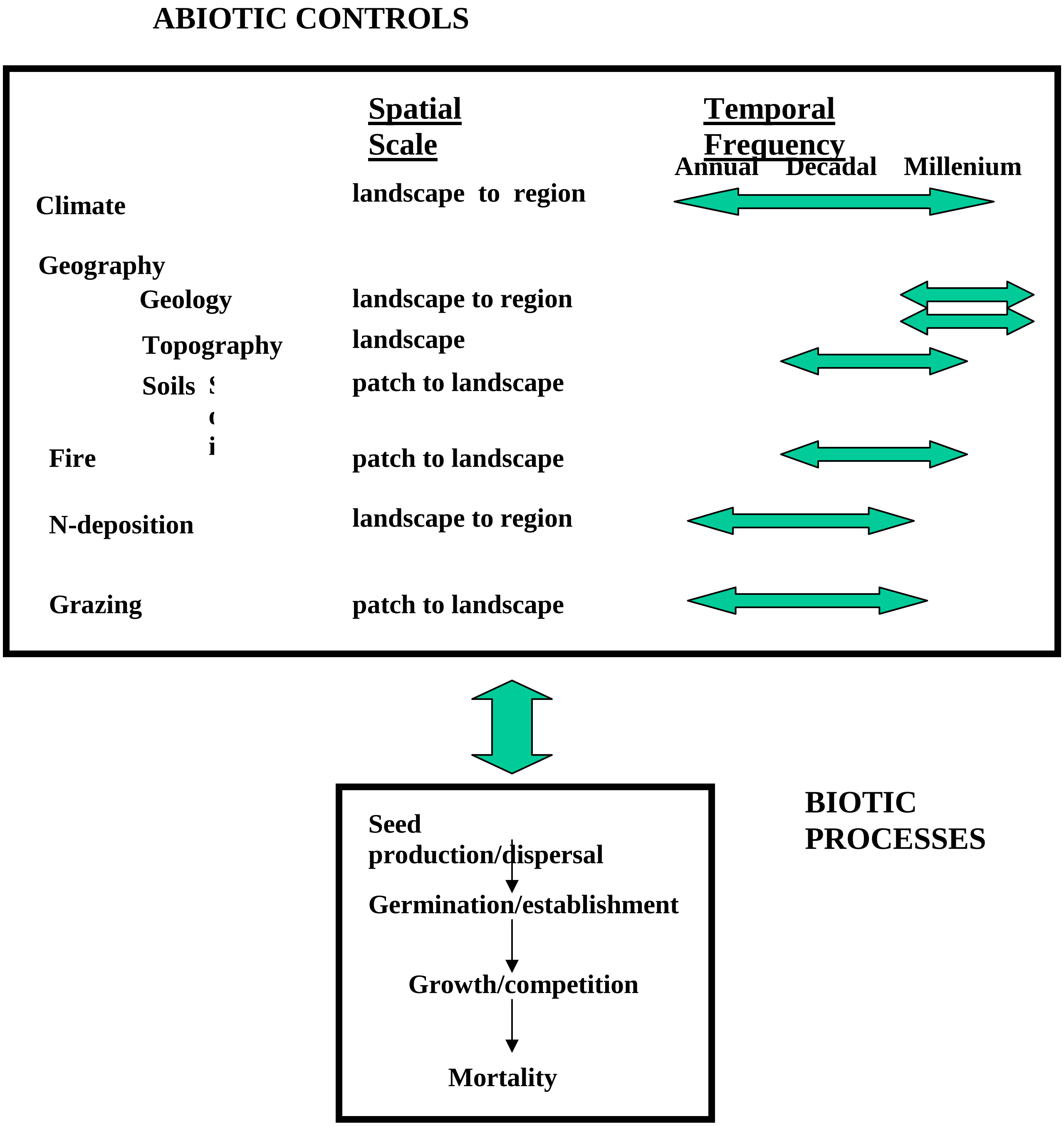


Figure II.1. Conceptual view of the abiotic controls on transitions of the Sevilleta region in terms of the spatial scales of their influence and the range of temporal frequencies for their behaviors. Broad climatic and topographic controls interact with local biotic processes to generate the observed patterns. Abiotic controls interact with each other (e.g., climate and fire) and biotic processes feedback to abiotic controls (e.g., NPP affects fuel for fire). There are numerous interactions among fauna, flora and local abiotic factors that influence the biotic processes.

II. Proposed Research

II.1. Introduction: Since the establishment of the Sevilleta (SEV) LTER program in 1989, our overall objective has been to provide ecological understanding and biophysical and mechanistic models of multiple transition zones interacting across a range of spatial and temporal scales. The dominant life forms of a biome have profound effects on ecosystems, and research at SEV is important in understanding how ecological processes are affected by the intermingling of life forms from adjacent biomes and the changes caused by movement of one life form into the habitat of another (Schlesinger et al. 1990, Kappelle et al. 1999).

The current proposal expands ongoing studies by initiating research focused at a mechanistic understanding of the control of ecological and ecosystem processes by external and internal drivers. Our five core study sites, placed in areas representing different life forms and zones of overlap (**fig. I.1, see Prior Support**), are information “nodes” allowing integration of abiotic and individual, population, community and ecosystem properties at specific points along transition gradients. Less intensive studies, experiments, surveys of other variables, and modeling across the intervening areas between core sites allow an extension of the understanding from points to the environmental gradients represented by SEV.

Goals: Our work seeks to address two major goals: 1) to understand controls on ecological properties and processes influencing transition zones between biomes (i.e., ecotones) and predict the dynamics of transition zones as these controls change over space/time; and 2) to determine the effects of transition zones on biodiversity at different spatial scales. For goal 1, a major organizing theme is that the different transitions are structured by the same general processes, but the disparate outcomes are the result of different environmental conditions (soil, disturbances, microclimate, climate, topography) interacting with plant and animal life history strategies (**fig. II.1**). **We predict that plant-level processes (recruitment, growth, and mortality) interacting with climate, disturbance, soils, and fauna cause the range of temporal and spatial patterns in vegetation and ecosystem processes that define the transitions between biomes. The resultant properties (structure, biomass, diversity, nutrient quality) and dynamics produce important feedbacks to these transition ecosystems.** The multiple transitions allow tests of the generality of these predictions by studying within (grass/grass, tree/tree) and between growth forms (grass/shrub, shrub/tree, grass/tree). Comparisons also can be made with the biomes at other sites.

For our second goal, the close association of multiple floras and life forms representing deserts to forests are assumed to create conditions promoting novel community assemblages and species interactions. **We predict that the high diversity of life forms and life-history strategies of the multiple biome transition zones will result in both a high local and regional pool of species, increase sympatry, and increase species population dynamics (increased variation in population densities).**

Our approach involves the integration of long-term monitoring, short and long-term experiments, broad-scale surveys, modeling, and remote sensing. These efforts occur over both short and long temporal scales and fine and broad spatial scales. Data from long-term measurements at our intensively studied core sites and remote sensing imagery are the backbone of the program. The spatial and temporal patterns from these data provide the principle means for relating abiotic and biotic controls, external and internal controls, and generating hypotheses for our experiments. Interpretations from these data form the basis for additional independent studies of our own and visiting scientists.

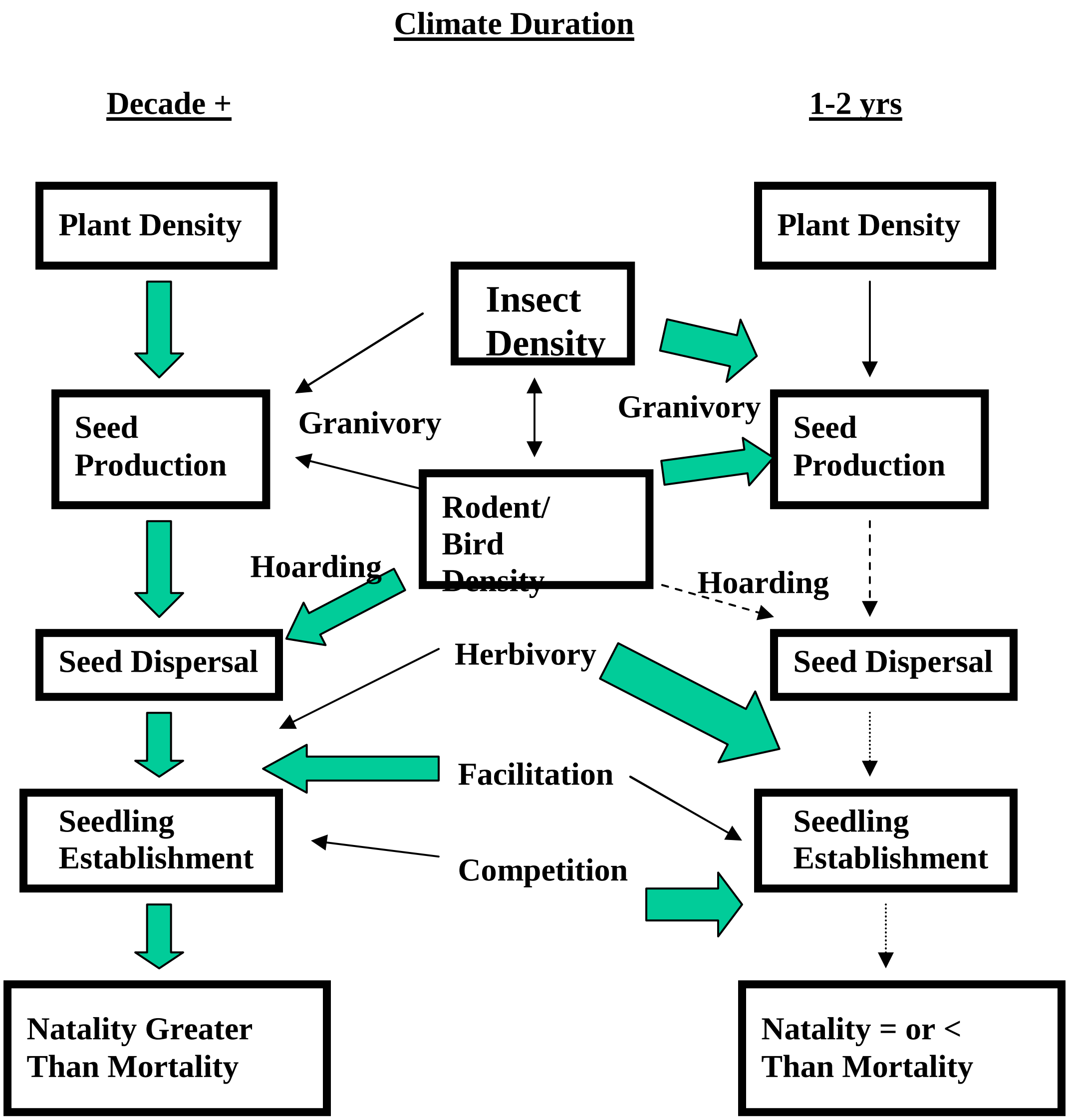


Figure II.2. Conceptual model for the interactions of climate and internal, biotic factors that lead to seedling establishment, mosaic formation and species range extension. The processes are in common for the different transitions on the Sevilleta; however, the ***relative*** strengths (indicated by broad or small arrows) varies. Long duration climatic situations, both drought and wet periods, will strengthen the positive feedback interactions indicated by broad, colored arrows. Drought causes this for desert species invading more mesic habitats (i.e., PJ, Shortgrass Steppe) and wet periods cause this for the mesic species moving into to dryer habitats. Short duration wet periods oscillating with dry periods inhibit one or more of the phases preventing a positive feedback from occurring for the entire sequence needed for invasion. The role of fauna varies from intensifying processes that contribute to positive feedback during the long climate duration to intensifying processes that result in negative feedback during short duration. Our experiments and long term monitoring are designed to test these relationships.

II.2. Conceptual Framework

II.2.A. Abiotic controls: Our conceptual model of dynamics at transition zones includes the effects of abiotic controls (climate, geography, fire, N-deposition, and grazing) operating at multiple temporal and spatial scales, and interacting with localized biotic processes (recruitment, growth, mortality, **fig. II.1**). These interactions between abiotic controls and biological processes result in complex patterns and dynamics in vegetation, ecosystem processes, and animal populations across the landscape. Climate, geography, and the interaction between the two give rise to the abiotic gradients that determine the distribution of organisms and the magnitude of processes at SEV. The interaction of climate and geography over the long-term give rise to general patterns of abiotic variables such as effective soil moisture. Deviations from average conditions occur at annual and decadal scales and provide the variation that generates system dynamics. Climate dynamics represent a natural, long-term experiment with a variety of periodic deviations that vary in intensity. These external controls provide a temporal template that structures the processes of the SEV and resultant patterns. The geology, topography, and soils are internal abiotic controls and represent the static spatial template determining where patterns and processes can occur under different climates. There are additional internal controls that are a combination of the above such as the spatial variability of precipitation over the long term that is influenced by topography, and patterns of effective soil moisture over the long term that are influenced by soil characteristics and the spatial variability of precipitation. Our studies now recognize additional internal abiotic controls (fire and nitrogen deposition) that must be incorporated into our studies. A new prescribed burning plan for the refuge will cause a predictable pattern of disturbance to contrast with natural fires.

II.2.B. Biotic processes: The mosaic patterns of the transitions are strongly affected by biotic processes. A major thrust will involve the fundamental aspects of biological controls that structure the patterns and processes of the associations of mixed life forms representing the transitions. We consider these controls to be internal in effect; however, we recognize that there are connections to biological phenomena at broader scales outside of the SEV. Examples are the sources of plant species (e.g., genes and seeds) from biomes constituting the biome transition zone, migratory birds that have periodic influences, and species with larger ranges than the scale of the SEV (e.g., large ungulates, other mammals). The patterns and processes of these biological associations also represent controls on the landscape in terms of influencing the abiotic features such as soil properties, evapotranspiration that feeds back to localized precipitation, albedo, etc.

We will increase our efforts to understand how the interactive roles of plant growth, seed production/dispersal, establishment, mortality, and competition play out on the spatial and temporal templates to form the patterns we see. The patch-mosaic patterns of transitions are likely to be a function of soils, microclimate, species dispersal patterns, faunal activities, and species establishment (Burke et al. 1999, Schupp et al. 1999); however, relatively little quantification has been performed on the processes leading to their formation (Schlesinger et al. 1996) and patterns at different scales (Gosz 1993). Figure **II.2** conceptualizes the interactions of climate and internal, biotic factors that lead to seedling establishment, mosaic formation, and species range extension, or conversely, reduction in these patterns. Fauna play special roles in these plant processes, and we will increase our studies of the rodents, birds, ungulates, predators, and invertebrates that influence plant community processes. We will

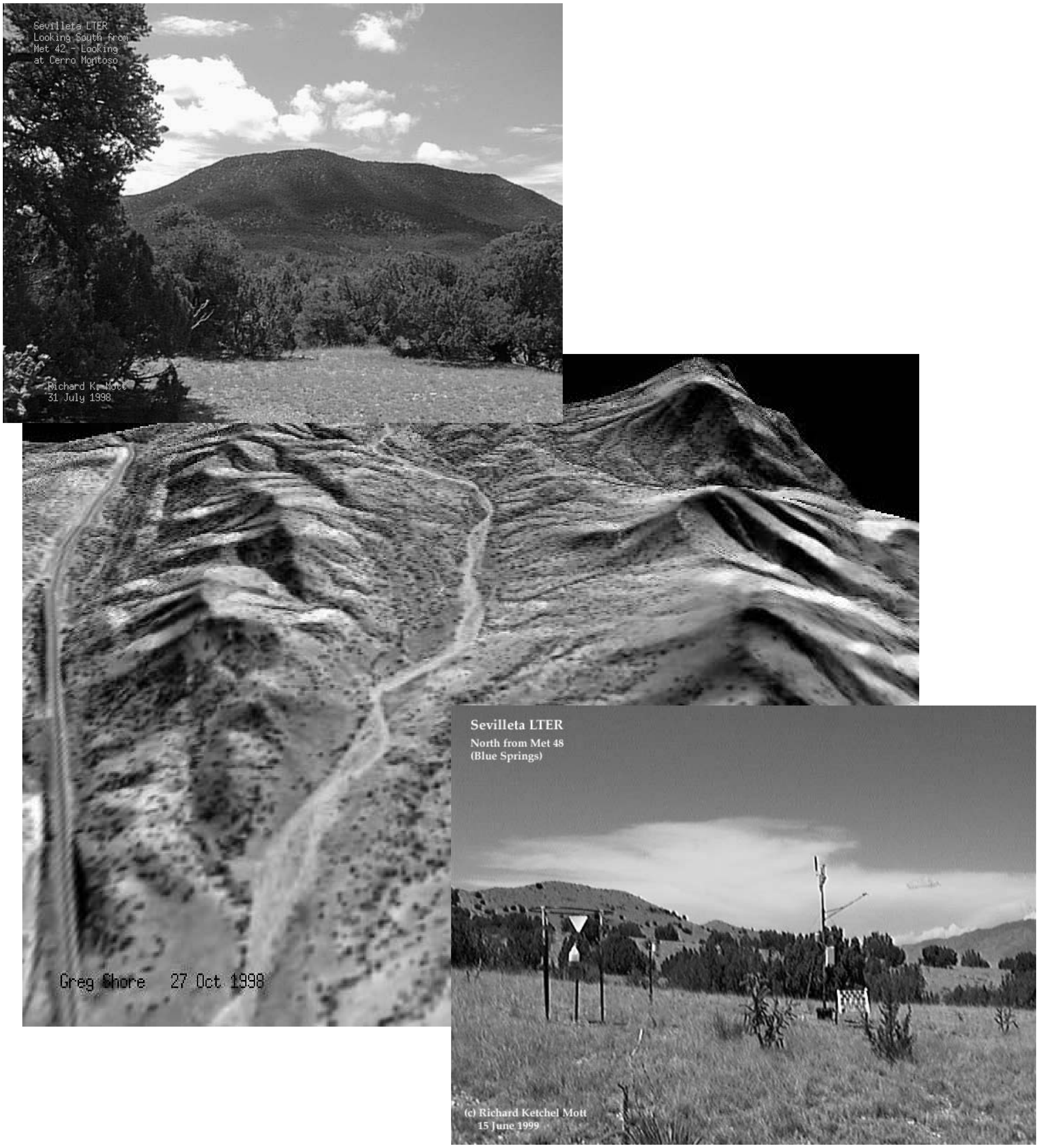


Figure II.3. ADAR false color image (1 m resolution) draped over digital elevation model for the study transition zone from Juniper savanna (lower photo) to Piñon-Juniper woodland (upper photo). This imagery allows studies of population demography and canopy cover of the woody species. Combining ADAR imagery with AVIRIS and low elevation, visible/infrared aircraft imagery allows species-level studies over large areas.

identify the complex interactions that occur among faunal groups, factors responsible for their population dynamics, and trophic food web dynamics. **We predict that species composition will vary dramatically over time; however, the changes are compensatory so that ecosystem-level variables are relatively constant** (Schindler 1977, Wardle et al. 1999).

Climate plays a role at each stage of **fig. II.2** by influencing seed production, faunal densities, and seedling mortality. While the same processes are involved in all transitions, the strength of each will vary in different transitions resulting in different patterns. In any case, **we predict that only during the decade-long periods of either drought or high moisture will the climate be consistent enough to cause all factors to amplify (i.e., positive feedback) conditions that contribute to species range extensions or contractions.** ENSO creates an important moisture variance pattern for this region. The time required for the full sequence of flower initiation, seed production, high faunal density, seed dispersal, seedling establishment, and plant growth for either desert or mesic species results in one or more of the ENSO phases creating an adverse climate situation. **During most decades, we predict that oscillations of wet and dry intervals produce conditions that adversely affect one or more phases needed for establishment. This causes competition, herbivory and/or granivory to be strong negative feedback processes that prevent additional mosaic development and species range extensions (i.e., static patterns).**

Finally, we will address the important concept of how patterns and processes of the biome transition influence biodiversity. The accumulation of information for species on our long-term study sites, broad-scale surveys over the many SEV habitats, and results from the independent studies of many scientists and students will create an impressive biodiversity knowledge base addressing our hypotheses and future studies.

II.3. The Sevilleta Transitions; Characteristics, Predictions, Hypotheses

Here we highlight our predictions/hypotheses that form the basis for an integrated program. Methods and experiments for our work are in II.4. We are focusing on dominant species in the three transitions because of their influence on system properties.

II.3.A. *Larrea* Shrub-Black Grama grassland transition: Northward movement of *Larrea* has occurred in this century with expansion into the Black Grama-Blue Grama (*Bouteloua eriopoda, B. gracilis*) grassland. The factors hypothesized to be responsible were a major drought during 1942-1957 combined with heavy herbivore pressure by cattle and prairie dogs and lack of fire. For the subsequent decades, all available evidence points to no further range extension but increasing density and size of shrubs in the mosaic patch structure.

II.3.B. Chihuahuan Desert Grass-Shortgrass Steppe transition: This transitional zone contains the overlapping occurrence of two dominant perennial grass species, *Bouteloua eriopoda* (Chihuahuan) and *Bouteloua gracilis* (Shortgrass Steppe). These species have different growth-forms and life-history traits (Gosz & Gosz 1996) with different effects on ecosystem processes. The presence of both species can be related to the oscillating climatic conditions with coexistence due to spatio-temporal niche partitioning dominated by biological interactions and soil properties. The wet 1980's resulted in increased density and dominance of *B. gracilis* in some areas, *B. eriopoda* in others. Annual plants and microbiotic crusts contribute greatly to the structure and dynamics of *Larrea* and grassland transitions.

II.3.C. Juniper Savanna-Piñon-Juniper (PJ) transition: This gradient ranges from Shortgrass Steppe with sparse Juniper canopy cover to forest with nearly complete canopy closure (**fig. II.3**). Significant differences occur for soil characteristics of grassland, canopy

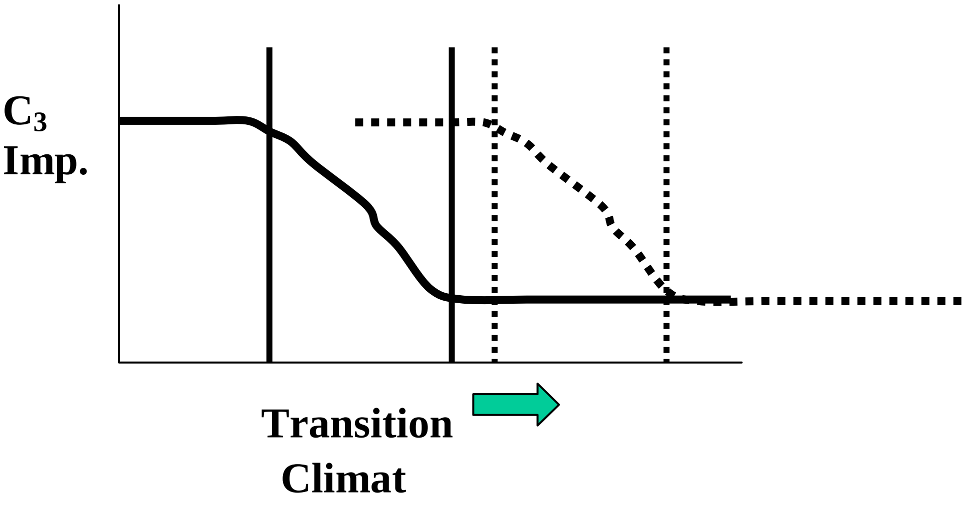


Figure II.4. Conceptual model of the importance values (e.g., density, biomass) of a life form (e.g., C_3 woody species) across a transition zone controlled by climate patterns. Modal climate patterns may be controlled by mountain topography through its influence on jet stream positions. In those cases, the transition location is fixed and life form distributions may be stable. Periodic changes in atmospheric circulation patterns may change the positions of jet streams causing the location of critical climate conditions to be shifted. Under those conditions, life forms may expand or contract to the new location of the transition climate. Other life history characteristics determine whether or not the life form changes back (hysteresis) to the previous transition climate location when jet stream positions return to a previous condition.

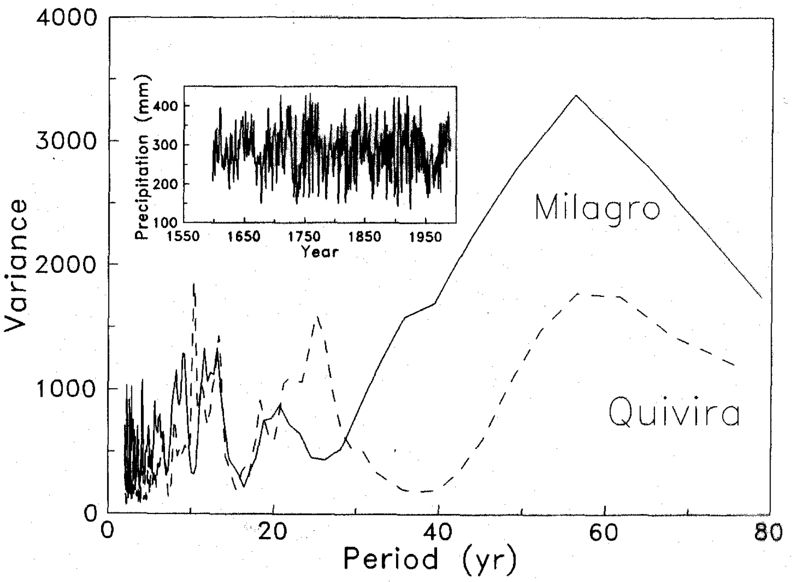


Figure II.5. Variance analysis of annual precipitation values derived from tree ring analyses from 2 sites on/near the Sevilleta. Peaks identify periodicities in drought/wet patterns that range from 2-3 yrs (El Niño/La Niña), 10-11, 22 and ~60 yrs. The 60 yr periodicity is a decade or longer drought that has profound impacts on woody species distributions. The last drought of this type occurred in the 1950’s.

interspaces and beneath both live and dead trees that greatly affect ecosystem processes and pattern dynamics. Also important are differences in the temporal dynamics and interactions among masting behaviors of Piñon Pine, Oaks and Juniper and interactions with fauna

Abiotic Controls.

II.3.D. Transition zone climate, topography: The influence of topography on climate is a primary factor in constraining the communities of the region. Ron Nielson stated in our first proposal; "*All major biotic regions in the world are controlled by climatic patterns that are, in turn, determined by airmass dynamics, that are, in turn, controlled by jetstream positions and temporal variability. Climatic periodicities occur through systematic meanderings of the jetstreams. Major mountain ranges act as foci in controlling those meanderings. The Sevilleta is in line with the longitudinal axis of the Rocky Mountains and is also at a low point in the mountain axis where jetstreams cross the mountains. Therefore, it is at a quasi-stable intersection of (at least) four major airmasses, i.e., a 'node' (Neilson 1986). The airmass gradients over the Sevilleta, a biotic boundary region, are topographically controlled.* **We predict that the topographically controlled storm tracks are a primary reason for the location of steep environmental gradients that cause the transition zones in the region of the SEV. We predict that conditions allowing the biome boundaries to move away from this transition zone (*i.e.*, node) are climatic deviations of a decade or longer. Also, different life forms will react differently to a given climatic event (e.g., drought).**

Figure **II.4** conceptualizes the location of the transition zone relative to adjacent biomes. During the majority of decades in the previous century, climate patterns were locked in at the 'node' position, and broad-scale movement of vegetation through the transition zone was inhibited. When infrequent but major changes in climate occur, the location of the transition-zone climate can be shifted large distances and there is an opportunity for vegetation movement. The most extreme drought of the past 500 years occurred from 1942-1957. This drought resulted in broad-scale plant mortality in grasslands, woodlands, and forests and accelerated shrub invasion of grasslands. At SEV this severe drought was one of a number of decade-long droughts in the past 500 yrs. There are several decadal to multi-decadal periodicities (e.g., ~11, 22, 60 yrs) of climate shifts (e.g., drought) demonstrated in climatic/hydrologic and tree-ring reconstructions from the Southwest (**fig. II.5**). *Of interest is the recent prediction that the Pacific Decadal Oscillation may be locking in the current La Niña (dry) phase for a number of years. This could be the return of a decade-long drought!*

Tree ring and climate analyses have identified a different climate pattern after 1976 (Swetnam & Betancourt 1998) when the Southern Oscillation (ENSO) locked into the negative, warm, and (for SEV) wet (El Niño) phase (Ebbesmeyer et al. 1991). Based on time series modeling, Trenberth and Hoar (1996) suggest that the unusual string of ENSO events since 1976 and the protracted 1991-1995 event should occur only once every thousand years. This period resulted in movement of Juniper and Piñon Pine to lower elevations than were occupied before the 1950's drought period. This climate pattern essentially linked events that occurred on a 2-3 yr frequency into a single 15 yr event. That pattern may now be followed by an extensive drought pattern if the La Niña prediction is accurate.

Precipitation and temperature interact at many scales to influence the range of patterns characteristic of a transition zone. The geographic depiction of biome space in New Mexico demonstrates where the narrow range of climatic factors allows multiple biome transitions; SEV is in a prime location to study this sensitivity (**cover**). The SEV vegetation map of primary associations show both the broad-scale pattern of interacting flora and the increased

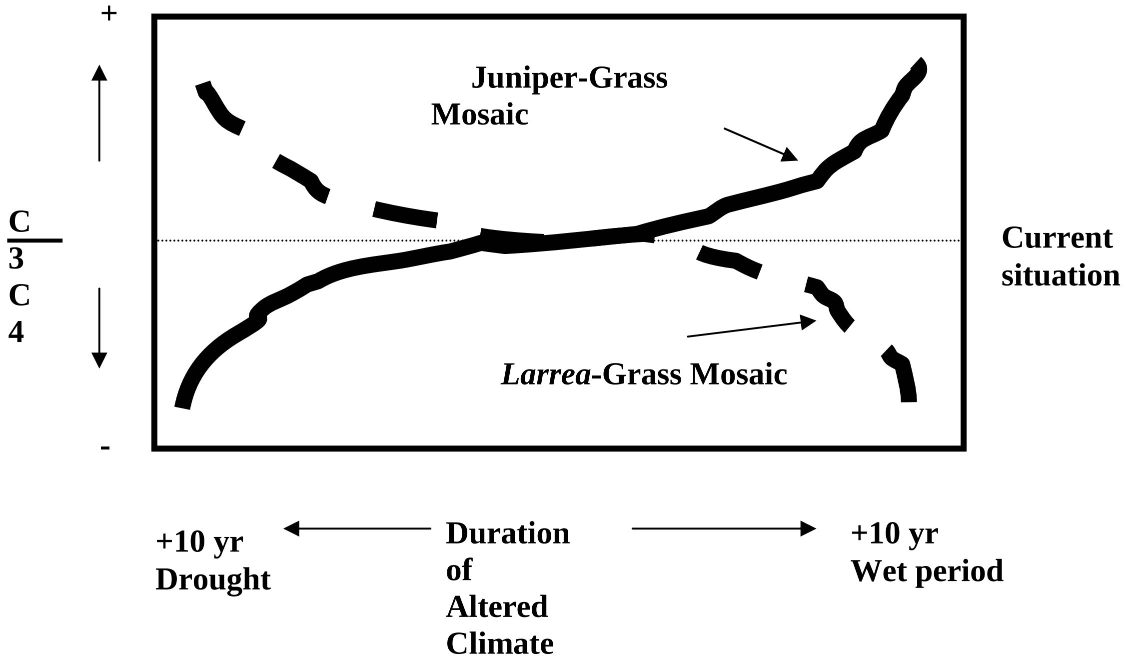
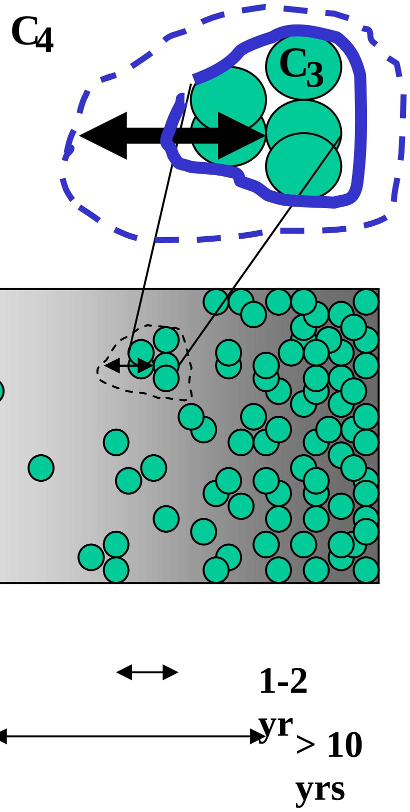


Figure II.6 (upper). The length of the period of changed climatic conditions is an important factor in the magnitude of expansion or contraction of life forms. The figure plots the change in the ratio of C_3 to C_4 life forms as a function of the duration of a climate shift. The relationship is predicted to demonstrate nonlinear and/or threshold behaviors as duration approaches a decade. Also important is that a decade of a certain climate will have opposite effects on the conifer vs. *Larrea* species. Drought will cause the C_3/C_4 ratio of the Larrea-Grassland mosaic to increase and that of the Juniper-Grassland mosaic to decrease. These shifts in woody/herbaceous ratios have important implications for many ecological processes in those habitats. (lower) The mosaic of patch sizes for a transition zone. Evidence of species movement (i.e., mosaic shift) involves establishment of individuals of one life form in the habitat of the other and an increase in all patch sizes of that life form. A decade may be required to cause measurable mosaic movement.



spatial heterogeneity resulting from local features (e.g., soils, topography, disturbance) that override the controls of climate and determine finer-scale features. Within the constraints of abiotic controls, transition ecosystems form a mosaic of small to large vegetation patches that have different dynamics and ecosystem properties as a function of the life histories of the dominant species of a patch and the ecological processes that cause patches to appear/disappear (Neilson 1986, Gosz 1991a,b). They represent a gradient of "island sizes" in the sense of islands of fertility or infertility. What is particularly interesting about recently documented dynamics at the SEV is that *Larrea* has moved into grasslands from drier sites while Juniper and Piñon extended into grasslands from upper elevation, wetter sites (Betancourt et al. 1993, Zlotin, personal comm.). However, these dynamics occurred during different decade-long periods. **Figure II.6** relates the differential effects of the duration of climatic conditions to dynamics that occur at the mosaic scale. Typical ENSO events occur too frequently and are of insufficient duration to affect the movement of the mosaic pattern. Oscillations between the wet and dry phases of ENSO prevent a directional change. A climatic pattern lasting a decade is likely to produce significant effects for the C_3 life form implying nonlinear or threshold conditions for extension or contraction of distributions. The conifer and desert C_3 species have opposite behaviors to a given climatic regime. This also occurs for the transition represented by perennial grass species from desert and Shortgrass Steppe. Sequences of cool, wet years favor Blue Grama, hot, dry periods favor Black Grama (Peters 2000).

The periodicities (**fig. II.5**) shown in the climate reconstruction are critical to our understanding of spatial and temporal interactions. El Niño and La Niña (ENSO) events typically are 1-2 years in duration, 2-3 times per decade. Major climatic deviations that last a decade or longer are less frequent (~60 yrs) but have more dramatic effects on vegetation movement. **We predict that *Larrea* range extensions into perennial grassland and higher elevations of the Sevilleta are limited to decade-long droughts and increased winter temperatures interacting with heavy herbivore pressure and a lack of fire. Modification of local microsite conditions after *Larrea* establishment causes a hysteresis effect so that a return to moist climate conditions, lower winter minimums, and reduced grazing pressure may not reverse the movement.** The recent 15 years of very wet conditions and absence of cattle and prairie dogs have not reversed *Larrea* movement at SEV.

At the scale of the mosaic pattern of patches that typifies the "edge" of a species or life form distribution (**fig. II.6**), microsite features control temperature, soil moisture, and plant establishment. For example, we expect that *Larrea* produces sufficient organic volatile emissions to raise minimum winter temperatures to or above –12 C, a critical temperature that can cause xylem cavitation (Pockman & Sperry 1997). Thus, the species may be able to control a primary factor limiting its distribution after critical population densities or patch structure has been achieved (**fig. II.7**). The patterns of these desert shrubs affect broader scale patterns of temperature as evidenced in the difference between actual nighttime minimum temperatures and minima predicted by dew points (Hayden 1998). This effect may not occur in PJ. **We predict that the woody C_3 vegetation of the PJ woodland extends and contracts its lower elevational distribution boundary in a reversible way (i.e., little hysteresis), as a function of alternating decade-long periods of high moisture or drought. In other decades, the change in climatic factors is not significant enough to cause major PJ redistribution in this transition zone. We also predict that more frequent climatic variations (*e.g.*, El Niño, La Niña) that occur on a subdecadal scale are not of sufficient**

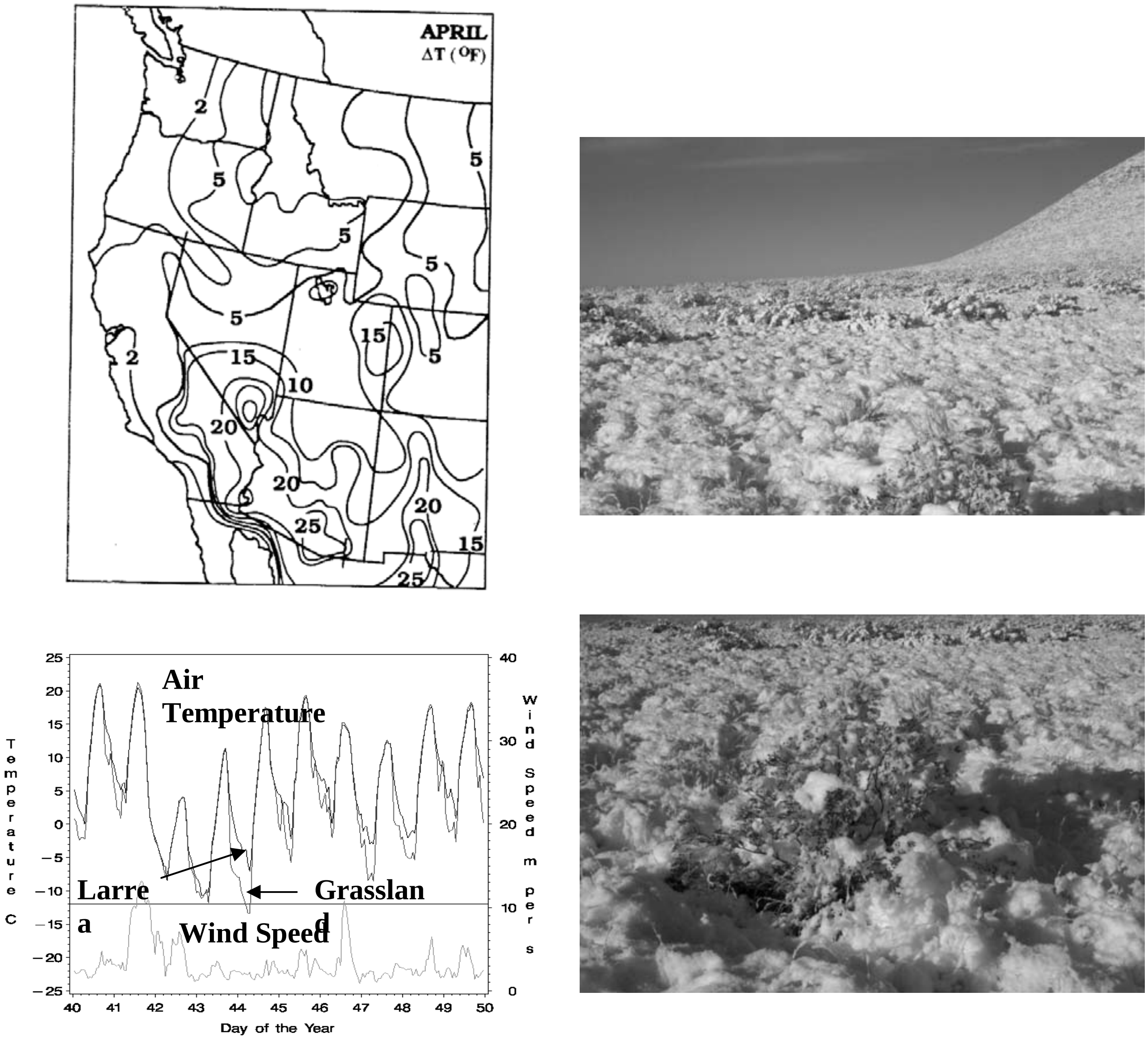


Figure II.7. (upper left) Hayden (1998) reported dramatic differences between dew point and minimum nighttime temperatures in this region reflecting the role that volatile organics play in holding heat in arid environments. Areas without significant volatile organics (e.g., grasslands) have a dew point temperature equal to the minimum nighttime temperature. This is especially important in areas where species may be at their distributional limits because of low temperature constraints. Pockman & Sperry (1997) identified a critical minimum temperature for *Larrea* of –12 C when cavitation mortality occurs. (lower left) February 1999 minimum air temperatures for weather stations in the *Larrea* habitat (blue line) and in the grassland habitat (red line) may differ by ~5 C during low wind speed conditions. The weather stations are only 5 km apart on flat terrain. These still, cold nights are the most critical for cavitation damage (horizontal line).

duration to result in vegetation redistribution by biological processes for either of the C_3 woody life forms (i.e., *Larrea*, conifers).

II.3.E. Transition zone soils: Soil moisture is one of the driving forces for vegetation patterns that, in part, is determined by soil properties. The soils on the SEV differ from many soils because of variable amounts of calcium carbonate accumulation. No studies have determined the influence of these carbonate accumulations on the hydrologic properties of soils. The effect of a given amount of precipitation is not the same across the entire landscape; some areas are much more sensitive to climatic change than others. For example, the area of the *Larrea* community has a strongly developed calcic horizon close to the surface, so changes in precipitation will not have a marked influence on water availability in these soils. The opposite is true for areas with a thick sand sheet at the surface. Mapping the soils on the basis of their hydrologic properties allows modeling the landscape response to given climatic events.

II.3.F. Evapotranspiration: Soil water is an important factor affecting the local atmosphere via the surface-atmosphere fluxes of water and energy. Because the soil moisture reservoir evolves on long time scales, soil moisture acts as a source of “memory” of past precipitation events. We suspect that these local processes affect the localized nature of precipitation events at SEV. The summer precipitation pattern has high spatial variability. **We hypothesize the land surface response to rainfall events and the attendant rise in soil moisture is dramatic-evapotranspiration and net radiation increase substantially following rainfall and feedback to influence localized rainfall.** We will study whether feedbacks from soil moisture patterns caused by localized precipitation and soil properties to the local atmosphere reinforce the spatial variability of precipitation.

II.3.G. Fire: The exclusion of cattle after the Wildlife Refuge was established in 1974 has resulted in a more fire-prone system. Substantial fire research has been performed on savannas and tallgrass prairies; however, arid systems may demonstrate different responses. In mesic grasslands, fire may open space for colonists (Collins 1987) whereas in arid communities, open space prior to burning is typical and burning may produce very different effects on diversity, productivity, interactions with climate, and fauna (McPherson 1995, Valone & Kelt 1999). Fire is an example of an intermediate-scale disturbance phenomenon (between coarse scale climatic variability and fine-scale organism-level processes) that has a significant impact on spatial temporal dynamics in these arid and semi-arid ecosystems. Although fire imposes direct effects on mortality, establishment and nutrient redistribution, fire also leaves landscape-level spatial imprints and associated feedbacks. Fire directly alters patch structure and ecotonal boundaries, which in turn has effects on dispersal, seedling establishment, future fire patterns and associated mortality not under direct climate control. Fire may also be very important in the enhancement of clonal, asexually spreading plants. **We predict that there is a fire-mediated patch structure that is imbedded within a complex mosaic that interacts with organism-level processes (e.g., masting and faunal dispersal), soils, and long-term climate variability (wet-period germination and establishment, vs. drought induced mortality).** Swetnam and Betancourt (1998) argue that periods of high ENSO variability (and/or amplitude) lead to more fire because of more frequent wet periods that increase productivity and fuel production. **We suggest an alternate to our previous prediction; climatic variations on a subdecadal scale (e.g., ENSO) can markedly influence the contraction of woody species if fire becomes a dominant factor.**

The effects of fire on native animals of Southwest semi-arid grasslands are poorly known, as are the subsequent effects of native herbivores on post-fire vegetation. Lightning-

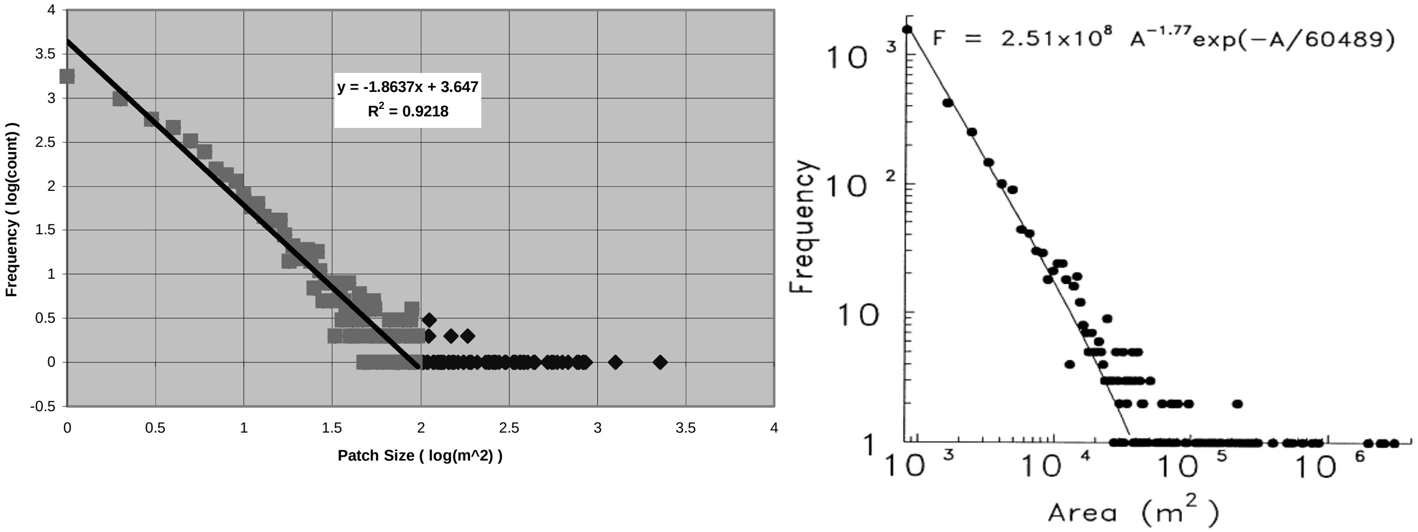
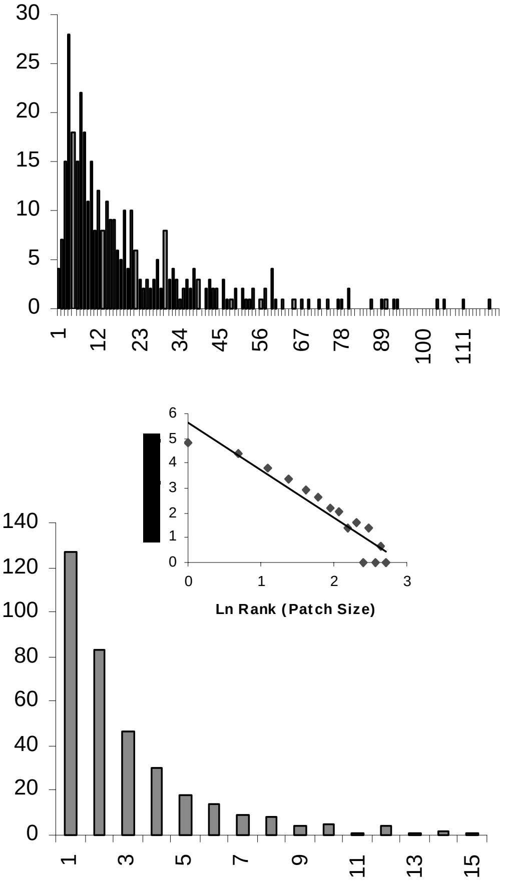


Figure II.8. Patch size distributions for *Larrea* shrub (left) and Piñon-Juniper (right) mosaic patterns. The straight-line portions of each log-log distribution identify patch patterns that are scale-invariant. The power law scaling indicative of stochastic processes is created by dispersal, mortality and episodic natality (Milne 1998). These results suggest important biological-ecological processes are involved in creating the distribution of patch sizes at ecotones. Resolution of the *Larrea* and PJ analyses are 1 m and 1 km, respectively.

Figure II.9. Power-law distributions of patch size or rank can result from simple grouping of data from log-normal distributions. These data are for Black Grama (fall 1991) from one of the line-intercept transects on the Blue Grama – Black Grama transition. The transects are 400m long and data are recorded are intercept measurements of each species, litter, soil and rocks at a 1cm resolution. The data provide estimates of percent cover for these variables, species diversity, and patch sizes of species. These data and variables will be used to test the models we are working on for better understanding the underlying mechanisms or processes that generate size.



caused fires have increased on the grasslands of SEV in parallel with increased grass biomass. Our previous experiments have demonstrated that fire causes mortality of small *Larrea* individuals but resprouting of larger individuals (Parmenter & Lightfoot submitted). **We hypothesize that a fire frequency of ~5 years will be sufficient to remove *Larrea* seedlings established during that period but allow recovery of Black Grama.** Increased fire frequency (through managed burns) is predicted to decrease all C_3 woody species invasions and/or cause a contraction of their range. **Fire is hypothesized to increase the competitiveness of Blue Grama in the Blue Grama-Black Grama transition.** We will continue our monitoring effects of natural fires and a new, periodic burning plan of the refuge to be implemented in 2000.

Biotic Processes:

II.2.H. Patch dynamics: Understanding causes of the mosaic patch structures of transition zones is fundamental to analyzing and predicting their dynamics. **We predict that a significant portion of the range of patch sizes in all transitions can be characterized by a power-law that identifies scale-invariant properties.** Figure **II.8** for *Larrea* and PJ are examples where the straight line in this log-log relationship is evidence of scale invariance. This observation raises two important questions. First, why do ecosystems organize into a state characterized by power-laws in the distribution of patch sizes? Second, what are the mechanisms originating and maintaining these patterns? The power-law may be a result of the grouping procedure. **Figure II.9** demonstrates how regrouping log-normal data from our long-term vegetation transect data from the *Larrea* and Blue-Black Grama transitions transforms the relationship. However, the research questions remain the same; what processes develop these basic patterns (log-normal/power-law) for species. **We predict that scale invariance for a significant portion of the distribution will be demonstrated by the mosaic patterns of different transitions but that slopes, intercepts, and portions that are log-normal will vary as a function of life history strategies and plant form.**

Analysis of the vegetation transect data also show scaling covariant processes at around 0.8-1.0 m depending on year or season (**see Prior Results**). Above the scale break we observed multifractal features inferring multiple controls, and below that a simple fractal. An important question is the range where scale invariance applies and where it breaks down as well as the corresponding mechanisms or processes responsible. **We predict that at the smaller spatial scales, spatial patterns and processes are controlled by biotic and local soil conditions, and at the larger scales, spatial patterns and processes are dominated by mixing of the smaller scale biotic and abiotic interactions including geomorphologic, climatic factors.**

There are a variety of ways to represent the size-frequency distribution of habitat fragments or patches. Li (1999) uses a simple power law relation to define the fractal distribution for quantifying the habitat fragmentation processes and gives a prediction about the fragility or vulnerability of landscape habitat using Turcotte's renormalization group approach. **We hypothesize that a more fragile or vulnerable landscape habitat may be associated with a smaller fractal dimension.** This approach of using fractal behavior for fragmentation may indicate the patterns most subject to change. The fractal measures the fracture resistance relative to the process causing fragmentation. **We hypothesize that there will be increased variation of information fractals from the Chihuahuan Desert shrubland to Shortgrass Steppe transitions**.

II.3.I. Plant processes: The dominant plant processes in our studies involve clonal expansion, seed production, seed dispersal, facilitation, establishment, mycorrhizal development, and

Figure II.10. Seedling establishment of Piñon Pine (left photo) in the Juniper savanna and Juniper in grassland (right photo) are hypothesized to have occurred during the 1980's by rodent/bird dispersal; a primary means of extending the range of these species when climate conditions allow successful establishment. The fence was a likely perch for birds for the Juniper seedling establishment. Other shrubs can serve in a similar manner.

The canopies of trees and shrubs can facilitate establishment of other species during conditions when climate may not allow establishment in open grassland situations. The Juniper (left photo) serves as a perch, cover for rodents, and source of seed for Junipers establishing in the understory. This effectively increases the "patch" size of Juniper and contributes to the mosaic of patch sizes that forms in a transition zone. The Juniper can also serve as a "nurse" plant facilitating the establishment of Piñon Pine seedlings in the organic-rich litter in its understory (right photo), extend the distribution of the Pine and the mix of Juniper and Pine; the PJ habitat.

mortality. For example, the limitation of plant water transport by xylem cavitation during drought and/or freezing stress is a primary cause of mortality of woody plant species at their distributional limits. **For *Larrea* at its northern limit, we hypothesize that cavitation associated with winter minimum temperatures is a primary factor in seedling mortality** (Pockman and Sperry 1997). For *Larrea* and other woody species (*Juniperus, Pinus*)**, we hypothesize that prolonged drought will act in a species-specific fashion to limit seedling establishment and drive episodic adult mortality.** Our studies will identify the drought-limiting aspects on seedlings vs. conditions that allow establishment under drought and wet conditions.

Although *Larrea* has stopped it extension into SEV grasslands, there has been an increase in density and size of patches (i.e., filling in). **We hypothesize that the increased density is due primarily to clonal expansion.** The shrub combines long-lived, clonal reproduction (Vasek 1980) with mixed-mating sexual reproduction (Simpson 1977). A recent survey of genetic diversity as measured by isozyme diversity in populations of Chihuahuan Desert *Larrea* show among the highest amounts of genetic diversity reported for angiosperms (Duran et al. submitted). SEV *Larrea* populations exhibit polymorphism in over 90 percent of their loci (10-11 loci). Each locus has an average of 4 alleles. This diversity is sufficient to use for multilocus genotyping to identify individual clones. **We hypothesize that clonal/seedling ratios will change in a nonlinear way across the mosaic pattern of the transition.** For example, **we predict that a critical density of plants is required to alter the microsite sufficiently to allow seedling establishment while clonal expansion may occur throughout the mosaic.** Many processes or activities may demonstrate nonlinear patterns related to critical patch sizes or formations in the mosaic.

We must also understand spatial and temporal variation in plant flower and seed production and factors influencing seed viability and dispersal. Seed production in the Juniper and PJ habitats is subject to large fluctuations due to masting behavior with each species reacting differently to environmental factors (Zlotin, unpubl data). The movement of the PJ association is a complex function of animal species that are dispersing the seeds, the physical structure of the community adjacent to the woodland (*e.g.*, perches for birds, shrubs or seedlings for cover for mammals), nurse plant requirements of the tree species (*i.e.*, facilitation vs. competition, Callaway & Walker 1997), and environmental conditions (Schupp et al. 1999, **fig. II.10**). The recent establishment of juniper seedlings in open grassland is primarily by the males for this species. Female plants require less extreme conditions (Ehleringer 1985). Successful male establishment may facilitate the subsequent establishment of female plants through roles of facilitation, and perches or cover for animal dispersers. **We predict that juniper sex ratios across the mosaic patch structure will be an index of the threshold conditions that influence other species and ecological processes.** Seed production will determine the potential for species to colonize new areas of SEV as environments change.

Plant growth and competition within and between species and life forms will be studied. **We hypothesize that spatial and temporal partitioning of resources allows the coexistence and co-dominance at transition zones. Changes in resources in time or space create the potential for large-scale shifts in vegetation and species dominance.** Blue Grama utilizes soil water at cooler temperatures, yet at similar depths as Black Grama, and *Larrea* uses water near the surface at cool temperatures in April and at deeper depths (20-30 cm) in May (Peters, unpubl). These studies on temporal and spatial differences in soil water uptake will be continued and used to parameterize the ECOTONE model for evaluating long-term

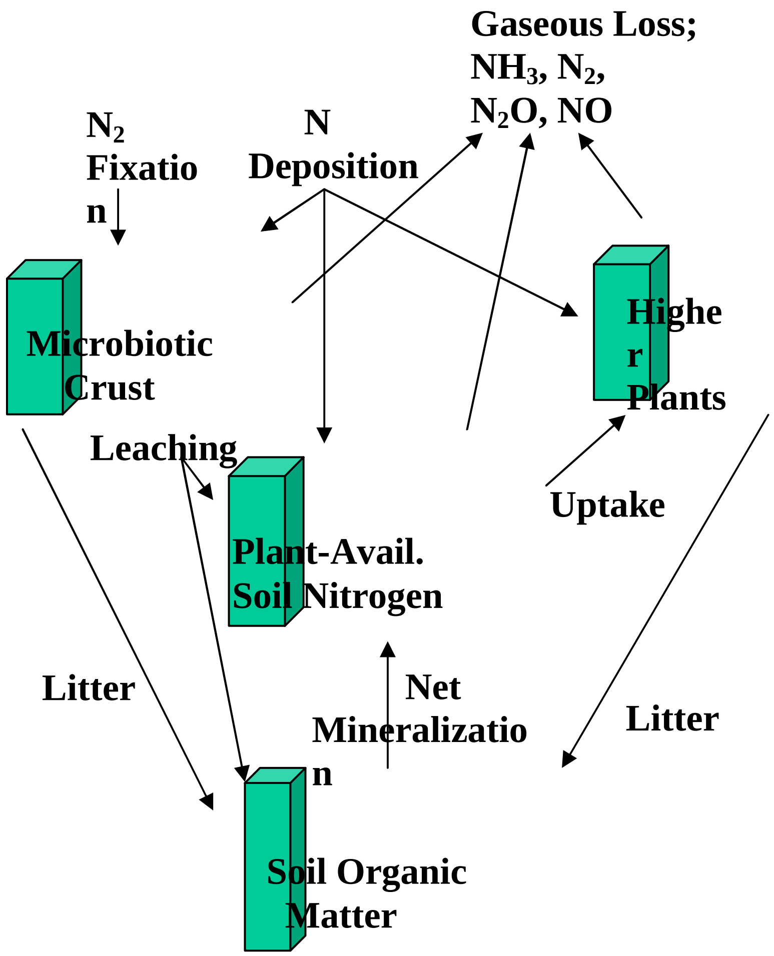


Figure II.11. Relationships among microbiotic crusts, higher plants, soil organic matter and nitrogen dynamics. Experiments at Sevilleta with double-labeled $^{15}NH_4{}^{15}NO_3$ demonstrated that ^{15}N is rapidly lost from the system in both grasslands and shrublands (Cross 1999). The magnitude of N supplied to higher plants by crusts, relative to atmospheric inputs and legume N-fixation, may be an important aspect of the dynamics of N and productivity in this system vegetation dynamics. Watering and drought experiments will be used to evaluate the types of precipitation events capable of initiating vegetative responses that lead to differences in establishment and growth. **We hypothesize that the desert grass species are more effective at utilizing rain events < 15 mm while Shortgrass Steppe grasses require the deeper soil moisture associated with rain > 15 mm. For growth, shrubs should require the greatest rainfall event (greatest soil penetration) and microbiotic crust activity the least (< 5 mm).**

Plant mortality is an important process that generates gaps in resource space allowing the occurrence of successional dynamics. We are removing the dominant species from plant communities in order to evaluate: 1) plant recovery and/or a change in species dominance; and 2) if dominant species with different life history traits have different legacy effects on recovery of other species through time. **We hypothesize that mortality of plants of different species will have different effects on community dynamics/ecosystem processes.** Our experiments will allow us to determine how many individuals are needed to create a "gap" in resource space that results in shifts in species dominance through time, and will test the gap dynamics conceptualization of Watt (1947) for semiarid and arid communities. We will also initiate studies to determine the causes of plant mortality.

Microbiotic crusts: Microbiotic crusts are central to resource dynamics, soil stability, and the hydrologic cycle in many arid ecosystems (West 1990, Eldridge & Greene 1994, Evans & Johansen 1999), however, there is a dearth of data on the distribution of crusts or the role they play in the SEV transitions. Although many authors (e.g., Harper & Pendleton 1993) assert that nitrogen fixation by crusts is a primary source of nitrogen to higher plants in arid ecosystems, Zaady et al. 1998 showed that nitrogen fixation by heterotrophic bacteria may sometimes play a larger role. In some cases, increased N availability may be attributable to crusts' physical effects (e.g., decreasing erosion and nutrient runoff). Zaady et al. 1997 showed that three ecologically-similar higher plant species were differentially inhibited from germinating in the presence of microbiotic crust, yet little is known about the influence of microbiotic crusts on other species of higher plants, or about the mechanism producing such effects, which could be biochemical (e.g., providing needed nutrients) or physical (e.g., the rough surface could inhibit root penetration, or conversely, it could provide a "safe haven" for seedling establishment). We hypothesize that: **1) crusts increase availability of essential nutrients at soil surface through biochemical mechanisms and/or physical mechanisms; 2) crusts effect germination of macrophytic plants through biochemical and/or physical mechanisms; and 3) crusts enhance mycorrhizal fungi associations with higher plants.** We will also elucidate the mechanisms (physical/biochemical) by which crusts produce effects. We will ascertain if microbiotic soil crusts present in the grassland significantly increase available N relative to legumes and atmospheric N deposition (Cross submitted). **We hypothesize that crust N fixation provides a similar amount of N over long time periods (e.g., decadal), whereas, legume N fixation is episodic.** During the previous decade, very high legume N fixation occurred during 1 year (i.e., ~ 10 g N m^2) from a massive germination event for two legumes (*Astragalus* spp). Legume abundance was low during other years. **We hypothesize that, regardless of source, N is rapidly lost via volatilization (fig. II.11).**

Characterization and mapping of the spatial distribution of crusts on our transitions will allow correlations with soil type, soil chemistry, and other physical conditions. The role of mycorrhizae also requires additional study and integration with other information. Current studies (Allen, unpubl.) are using minirhizitron techniques to analyze root and mycorrhizal production and turnover rates under control and N additions for the dominant species in our

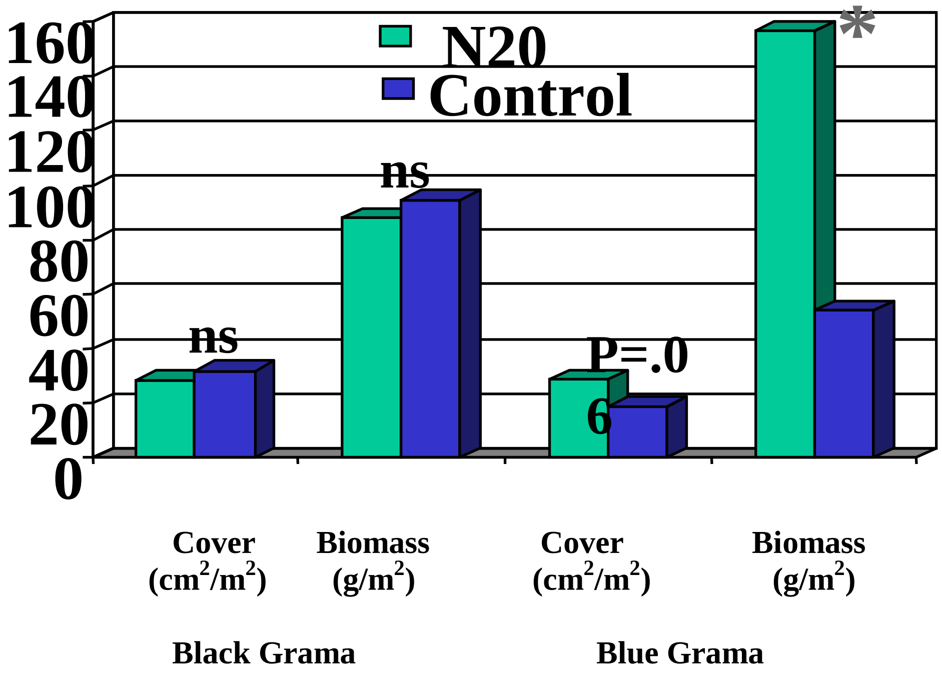
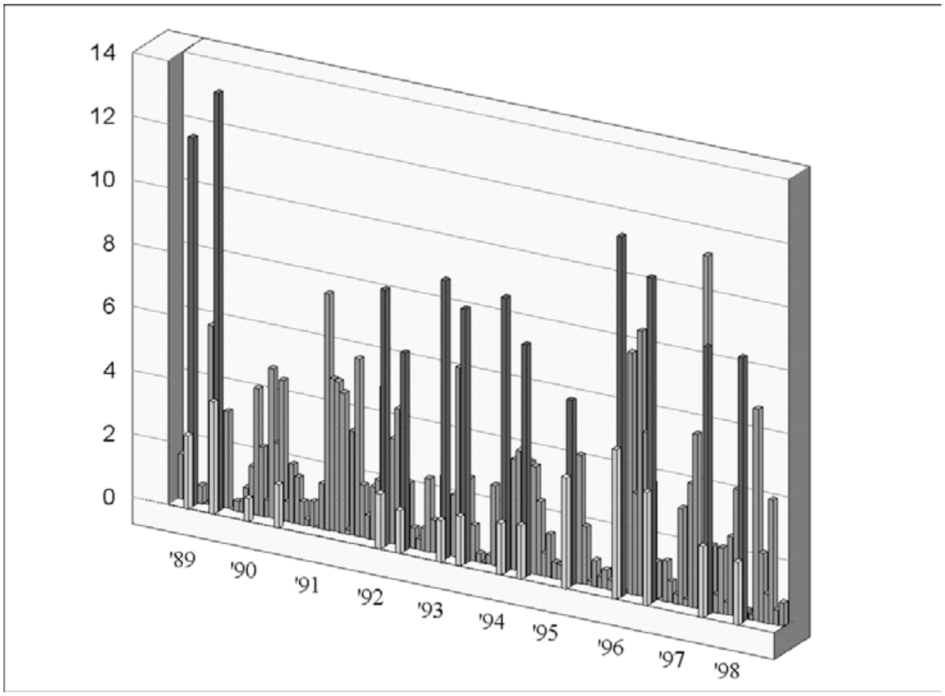


Figure II.12. (upper) Effects of N fertilization (20 kg/ha) on canopy cover and green biomass of Black and Blue Grama, summer 1998. Blue grama responded to a much greater degree to increased nitrogen because of its microhabitat conditions involving greater soil depth and soil moisture. (lower) Relationships among annual precipitation in the grassland transition. Potential mineralizable nitrogen was determined in laboratory bioassays of 0-20 cm soil samples over a 35 week period. Field available nitrogen was the initial nitrogen level of the sample. Patterns of potential mineralizable and field available nitrogen were similar over the decade in response to major drought (La Niña) and wet intervals (El Niño). Available nitrogen increases markedly during drought years and is reduced during the subsequent moisture years (e.g., 90-91), principally by plant uptake. This results in wet periods having a more favorable combination of nitrogen and water for plant growth. Other evidence suggests that prolonged periods of above normal moisture can deplete nitrogen availability to levels that may constrain plant growth.



(blue) precipitation in cm
(red) potential mineralizable N
(in mg/kg)
(yellow) field available N
(in mg/kg)

transitions. **We hypothesize N enrichment by itself will favor certain species, increase root and hyphae disappearance, decrease mycorrhizal hyphae and exacerbate subsequent drought conditions in soils** (**fig. II.12**). Increases in N deposition are predicted to alter basic patterns related to vegetation. **We hypothesize that for Piñon and Oaks, there will be a shift in EM fungi from those capable of N mineralization to N scavengers. Increasing nitrate will favor grasses and reduce AM infections. There will also be a shift from *Scutellospora* spp. to *Glomus* spp.** Altered microsites by mosaic patch structure also influences mycorrhizal activities. **We hypothesize that increasing nighttime minimum temperatures will facilitate a species shift in both Arbuscular Mycorrhizae (AM) and Ectomycorrhizal (EM) fungi. In AM, the change will be from *Scutellospora* to *Glomus*, in EM from N_{min} to nitrogen scavengers (N_s) species.**

II.3.J. Fauna processes: Animals have important roles in damping or accelerating changes in biome transition zones, including soil disturbances, seed dispersal, and trophic interactions. Animal-mediated processes operate at many spatial and temporal scales, dependent upon species' mobilities and habits, diet preferences, habitat quality, and climate conditions. Faunal interactions with climate, soils, and flora may prove critical to transition movements; e.g., while the drought of the 1950's caused water stress in Junipers and pines, the proximate cause of tree mortality was insect attack. In contrast, much of the *Larrea* invasion into SEV grasslands may be facilitated by rodent mound formation, and removal of plant biomass by herbivores reduces fuel loads and risk of fire.

***Small mammals—population dynamics*:** The diversity and abundances of small mammals at SEV demonstrate considerable spatial and temporal variation that is episodic and non-synchronous (Parmenter & Van Devender 1995, Parmenter et al. 1995). Such patterns in vertebrates are widely observed (Cody & Smallwood 1996), and are likely linked to landscape-level processes (Bissonette 1997, Barrett & Peles 1999). These dynamics may be due to either: 1) actual resident populations on the study sites exhibit large *in situ* changes in abundances, ranging from low densities (below detection limits, or apparently absent) to high densities due to changes in food, climate or predator/disease prevalence; or 2) movement of nonresident individuals from adjacent habitats into and through the areas with permanent trapping webs. **We hypothesize that the immigration of nonresident rodent species is the primary factor in major variances in local population dynamics.** We predict that this dispersal pattern is evidence of a "regional" species pool that is influenced by different factors than those affecting the local study sites. Food resource availability at the local scale may not be correlated with dispersal patterns from regional species pools. We believe that the complexity of life forms on the SEV transitions that cause increased separation of resources in time and space contributes to the larger regional species pool. This also may explain a higher level of apparent sympatry than characteristic of other areas of the region.

***Small mammals—seed dispersal*: We predict the role of the fauna in dispersing seeds through scatter hoarding and fecal deposits** (Vander Wall 1990) **is a dominant process in extending the ranges of species under favorable climate conditions.** Diet studies and surveys for caches and fecal seed content of fecal material will document this process.

***Small mammals—herbivory/granivory*:** The long-term, small mammal exclosure study (SMES) was initiated at SEV and Jornada LTER sites in 1995 to document the interactive effects of native small mammals and climate on the local biotic communities. An additional site was installed at the Mapimi Biosphere Reserve, Mexico, in 1996. **We hypothesize that small mammals have a significant role in maintaining the existence of shrub islands and**

Figure II.13. Recent development of a prairie dog town at the north boundary of the Sevilleta Wildlife Refuge (looking north). The vehicle is at the Sevilleta fence line with private land in the background. The invasion by Gunnison's Prairie Dog occurred during the past 2 years from the private ranchland in the background and now has created a colony of ~400 mounds. The invasion occurred in a low topographic area dominated by low stature grasses, primarily burrow grass (*Scleropogon brevifolius*) and involved moving into existing K-rat mounds (*Dipodomys spectabilis*, lower photo), another keystone species. The studies of this invasion include the effects of prairie dogs on K-rats, vegetation composition and productivity, other rodent species, nutrient cycling, microbiotic crusts, invasion potential by the desert shrub, *Larrea tridentata*, and the influence of fire.

spatial heterogeneity of *Larrea* shrub communities. **We hypothesize that removal of small mammals from grassland sites results in an increase in woody shrub species, and removal of small mammals from desert shrub sites results in an increase in grasses.**
***Birds—granivory/frugivory/dispersal*: We predict that the influence of granivorous bird populations is directly related to ANPP and seed production.** Large populations of migratory birds only locate in transition areas at times of high seed production (mast years).
***Arthropods*:** Population changes for arthropods also are important controls influencing seed dispersal, granivory, and herbivory. **We hypothesize: 1) arthropod populations are positively correlated with precipitation and Aboveground Net Primary Productivity (ANPP); 2) different arthropod trophic groups exhibit different temporal responses to precipitation and ANPP. Specifically, herbivores respond within a season, detritivores exhibit a one-year lag time response, and predators do not respond; and 3) populations in mixed life form habitats are spatially and temporally more erratic than in sites with a single dominant life form.**

For all the SEV herbivore taxa, selective herbivory may have a significant effect on plant species composition and vegetation structure of transition communities. Herbivores in semi-arid environments also consume a greater portion of the standing plant biomass than in mesic ecosystems. **We hypothesize that under climatic conditions limiting NPP for a given life form, herbivory is an important biotic factor regulating the distribution of certain plant species across transitions.** We propose to determine activity patterns, diets and consumption rates of some of the numerically dominant herbivores at our core sites, and use energetic/metabolic models to assess potential magnitudes of herbivory. **We hypothesize: 1) levels of herbivory are correlated with levels of ANPP across space and time; 2) rates of herbivory are higher in the transition areas (i.e., mixed lifeforms) relative to non-transition communities; and 3) selective herbivory on plant seedlings significantly affects community composition.** Over the long-term, seedlings of numerically dominant plants at each of the core study sites survive in transitions only when protected from herbivores. While herbivory and granivory significantly reduce seed availability, periods of favorable climate conditions produce excess NPP and seed abundance resulting in a net increase in dispersal and establishment.
Prairie Dogs/Bannertail Kangaroo Rat (K-rat) studies: Studies of these two “keystone” species warrant special attention (**fig. II.13**). Prior to poisoning in the 1960’s, huge populations of Gunnison’s prairie dogs were present on SEV grasslands (R. Foard, USADC, pers. comm.). We have little knowledge of the ecological effects of this species in this region, how the ecosystem is altered through time, and interactions with other keystone species. We propose to study a colony of Gunnison prairie dogs (*C. gunnisoni*) expanding voluntarily into the SEV grasslands, as the long-term changes may prove substantial. **We hypothesize: 1) species composition and abundance of plants, grasshoppers, ground-dwelling arthropods, lizards, and rodents vary directly with prairie dog abundance; 2) disturbance is the primary factor affecting these relationships; 3) similar arthropod assemblages utilize prairie dog and K-rat burrows; 4) prairie dogs utilize K-rat burrows or disturbance patches and eventually reduce K-rat density; 5) prairie dogs prevent the establishment of woody plant species by removing seedlings of those plants and maintaining short-grass communities around their burrows.**

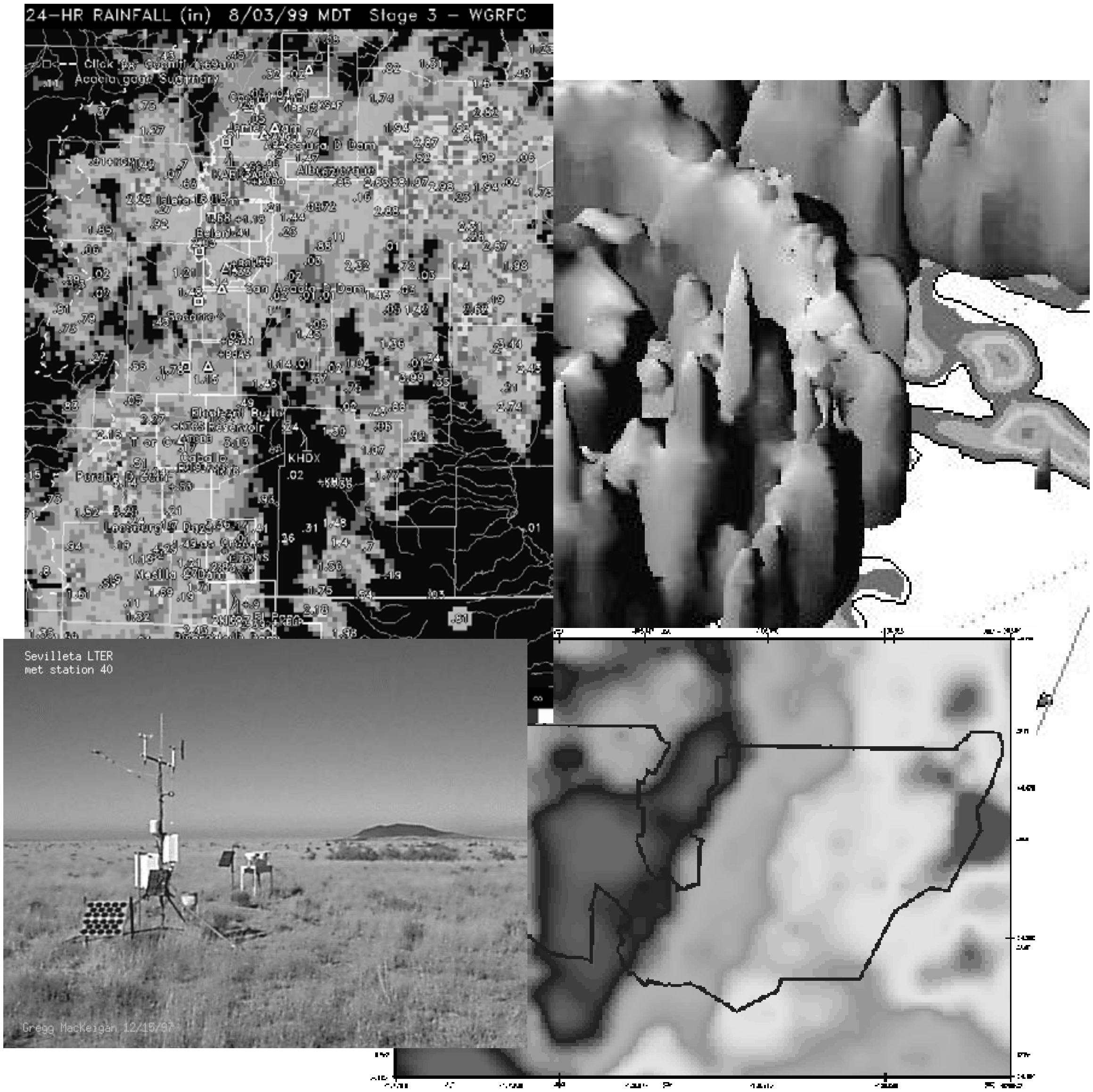


Figure II.14. Local to regional-scale precipitation is a crucial driver in the ecology of the Sevilleta region and will be estimated by a combination of technologies. Arrayed are NEXRAD (upper left), TRMM (upper right), lightning-location estimates (lower right) and weather stations (lower left). These provide a combination of verification/validation for each other and estimates for different spatial-temporal scales. For TRMM, there is a five-year research agreement with NASA to develop satellite image, data, and information products for resource applications in the Upper Rio Grande Basin. Two of the prototype products are: 1) TRMM rainfall and rainfall rate maps for the Southwest, and 2) ET maps based on TM data processed with Penman ET Model parameters. Validation requires deploying a nested array of low-cost rainfall event recorders and sensible temperature and relative humidity devices to complement weather station data. Evapotranspiration and energy fluxes will be measured by Bowen Ratio stations.

II.3.K. Ecosystem properties and feedbacks: The basic properties of transitions have important consequences for production and fate of organic matter, resource availability, trophic dynamics, and relationships with disturbance.

NPP**:** We intend to utilize ANPP data to document the relationship between climate and plant productivity variation across the transitions. **We hypothesize that ANPP and root turnover are positively correlated with annual precipitation (APPT); however, the high temporal and spatial variability in NPP as well as time lags in the responses of plants to precipitation result in a nonlinear relationship** (Sala et al. 1988). Years with similar annual precipitation can have very different ANPP. **We hypothesize that desert grasslands and shrublands operate differently than semiarid to mesic grasslands and will have a different quantitative relationship with precipitation.** Precipitation in certain seasons or in previous years may be a better predictor of ANPP as well as controls by N availability and time since disturbance (e.g., fire, drought).

Decomposition**:** Our long-term studies on the fate of organic matter produced by the dominant species have demonstrated marked variation, not directly correlated with annual precipitation. **We hypothesize that for arid transition areas, climate conditions during the year the material was produced are equal in importance to the climate conditions during the subsequent decomposition period for desert systems.** Aridity reduces the influence of moisture and temperature and increases the influence of tissue quality on arthropod involvement in the decomposition process. The dramatic differences in annual precipitation will separate these influences. **The mesic habitats are hypothesized to demonstrate a higher correlation between decomposition and climate conditions during the decomposition period.**

N Dynamics: In semiarid landscapes, the ratios and spatial arrangements of herbaceous to woody plant cover (trees and shrubs) and associated biomass are a major determinant of many ecosystem processes (Davenport et al. 1996, Breshears et al. 1997, Martens et al. 1999). **We hypothesize that % woody canopy is directly correlated with total ANPP, canopy N, and N mineralization for Juniper and PJ habitats but is uncorrelated with those variables in *Larrea* habitats.** In either case, the mosaic of patch sizes and their N relationships allow the scaling of these processes to the landscape. Previous sections have discussed N dynamics associated with microbiotic crusts.

Increased nutrient deposition has created additional spatial patterns at the scale of the SEV (**Prior Results**). Analyses of intra and interannual patterns of available nitrogen show distinct patterns with dry and wet periods. Drought results in increased levels of N and the following wet period has a favorable combination of N and moisture for plant growth (**fig. II.12)**. A sequence of wet years can deplete N to levels that limit NPP. **We hypothesize that the subdecadal oscillations of these wet and dry periods favors the persistence of the transition; decadal periods of drought will favor the desert species that can more opportunistically use available N under reduce or infrequent precipitation events.**

II.4. Long Term Monitoring and Experiments

We have used **predict** and **hypothesize** in describing our research. Phenomena we predict will be studied by long-term and broad-scale monitoring and observations. Hypotheses will be tested using monitoring, specific experiments and manipulations. We have proposed a number of new projects; however the increased number of PIs, technicians, and interactions with other agencies gives us confidence that we can accomplish them.

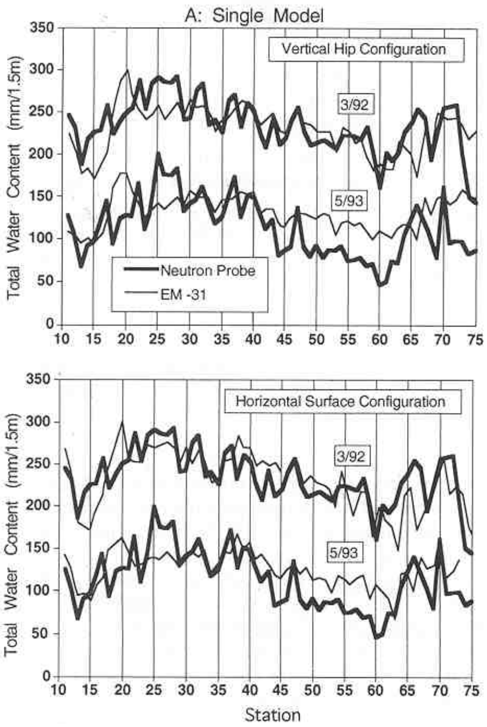


Figure II.15. (top left) Electromagnetic induction has become the method of choice in regional vadose zone hydrology and soil science since it is the only method that allows rapid field scale determination of major relative changes in soil type and soil water regime (Hendrickx et al. 1992; Kachanoski et al. 1988, 1990; Sheets and Hendrickx 1995). For the delineation of different soil types in the Sevilleta and their soil water regime we will use the EM38 and EM31 ground conductivity meters that measure the apparent electrical conductivity of the soil using electromagnetic induction. The EM38 and EM31 work without electrodes and do not need ground contact, thus measurements can be taken at walking speed (left figure). The EM38 and EM31 provide depths of exploration to approximately 1.5 and 6.0 m, respectively. The EM31 has been used successfully for the determination of soil boundaries and soil water content along the Jornada transect in southern New Mexico (top right). Bowen Ratio stations (lower left) will quantify water and energy fluxes at our intensive study sites.

II.4.A. Abiotic controls

Precipitation/Evapotranspiration (Moore, Craig, Small, Hendrickx, Morain): Precipitation is estimated from our weather stations, lightning location, NEXRAD and TRMM (**fig. II.14**) and will be used to project the nutrient deposition patterns for the study region. Evapotranspiration will be quantified through a network of Bowen Ratio stations, imagery, and modeling. Field observations and numerical experiments will quantify the length scale at which soil moisture and surface flux anomalies are organized. Continuous data will be collected from micrometeorology/hydrology sites in grassland, *Larrea*, and Juniper savanna environments on precipitation, latent and sensible heat flux, net radiation, surface temperature, and soil moisture at multiple depths. Broad-scale soil moisture patterns will be measured with electromagnetic techniques to relate to soil patterns (**fig.15**). The Biosphere-Atmosphere Transfer Scheme (BATS) will model a temporally continuous, synthetic record of the spatial distribution of soil moisture and surface flux anomalies, to “fill in the gaps” between the micrometeorology sites.
Microsite temperatures (Gosz, Small, Moore): We have mapped *Larrea* patch densities in the study region and will establish an array of ~ 100 max-min thermometers to identify the patch conditions (size and density of *Larrea* individuals) that influence the pattern of higher winter minimum temperatures. These conditions will be related to the distribution patterns of clonal and seedling individuals, mycorrhizal species and faunal activity within the mosaic.
Soils (Shore, Francis, Harrison, Hendrickx, NRCS): We will improve the current, coarse resolution soils map by developing a detailed map of surface soil characteristics using a combination of imagery and a new soil survey. We expect that the NRCS will complete a detailed (Level I) soil survey of the Sevilleta and Jornada LTER sites during the next five years in collaboration with LTER scientists. In addition to the standard dataset associated with the survey, we would be particularly interested in including detailed information on the depth, thickness, carbonate content, stage of development, morphology and structure of calcic horizons. We will describe soil profiles and determine the chemical and hydrologic properties for the primary associations of the transitions. Initially, low altitude, airborne sensors (AVIRIS and MASTER) will be used to model and test soil classification techniques over a small area. The results from this intensive sampling will be extrapolated to the extent of the refuge boundaries through the use of additional AVIRIS data and the ASTER and MODIS sensors aboard the new Terra satellite. Classification of soil characteristics will proceed based on information extracted from the remaining pixels. Ground sampling will be based on the classification to describe soils properties and classification.

II.4.B. Biotic processes

NPP (Lightfoot, Shore, Friggens, Zlotin, Gosz, Allen, Muldavin): The high spatial variation in plant communities caused previous sampling methods to be inadequate. We initiated new ANPP studies in 1999 using the volumetric methodology developed at the Jornada LTER site (Huenneke, Clason, & Muldavin submitted). PJ productivity will be evaluated with seasonal and annual dynamics of trunk increment using dendrometers and canopy height measurements plus quantification of twig and seed productivity and litterfall. These data will provide the basis for volumetric estimates of productivity (Chojnacky 1997). Nitrogen and C analyses will be made on samples from all collections. We have 90 band dendrometers placed on Piñon and Juniper individuals in our core sites in Juniper savanna and PJ.

Root studies will continue using minirhizitron techniques to analyze root and mycorrhizal production/turnover studies. We have minirhizitron tubes placed under Piñon (24), Juniper (24), *Larrea* (10), Blue Grama (10), Black Grama (10). An additional 48 are

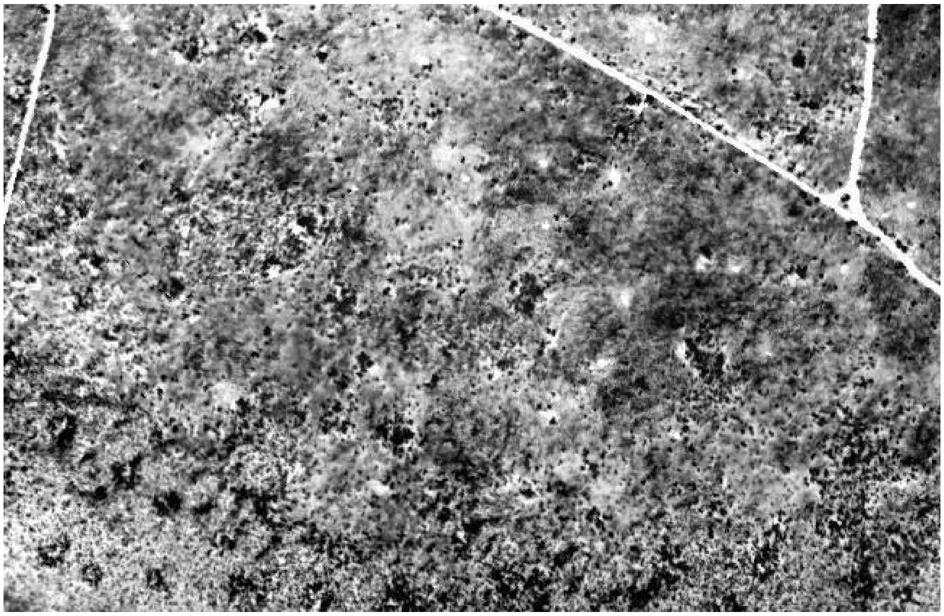
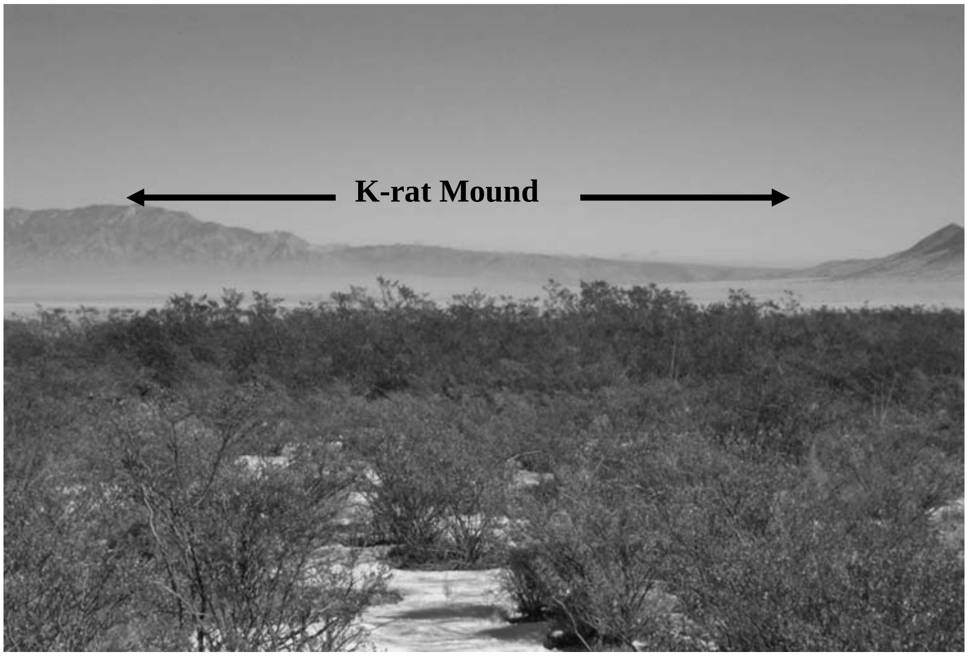


Figure II.16. (upper) False color ADAR imagery (1 m resolution) showing *Larrea* shrub patches (in red) associated with Kangaroo Rat (*Dipodomys spectabilis*) mounds in the *Larrea*-grassland transition zone. The patches formed on these mounds contribute to the scale-invariance power law that describes the frequencies of patch sizes in the mosaic for the transition zone. (lower) *Larrea* shrubs around the Kangaroo Rat mound within the *Larrea* dominated habitat are larger and more dense suggesting the role of these animals on increasing the density of shrub individuals, most likely through clonal activity. The mounds also have changed soil properties that may contribute to vegetation differences.



under N fertilized Piñon and Juniper. We will add 20 across each of the transitions (*Larrea*/grass; Oak/grass; Juniper/grass) and 10 under N fertilized Blue Grama plants. We will evaluate changing diversity of soil organisms, esp. mycorrhizae in response to N additions.

Spectral Vegetation Indices (SVIs) derived from satellite imagery have been used to estimate several important ecosystem properties including LAI, biomass, and ANPP (Begue, 1993; Box et al. 1989; Paruelo et al. 1997). However, the gold standard of SVIs, the NDVI, is known to be deficient in landcover types exhibiting low canopy cover due to the strong influence of soil reflectance on the integrated spectra (Todd and Hoffer 1998). Numerous other SVIs, such as the Soil-Adjusted Vegetation Index (Huete 1988), have been developed in an attempt to mitigate soil background influences, but many require site-specific or scene-specific calibration. We propose to evaluate a suite of ratio-based SVIs and orthogonal SVIs for best performance and efficacy in estimating LAI, biomass, and ANPP in each of the major habitats. We will utilize monthly Landsat 7 TM imagery as the basis for these stand level estimations, and existing NPP allometry plots, Eddy Covariance/Bowen Ratio stations, and new PJ-NPP ground-based measurements for validation. As an EOS Land Validation Core Site, we will scale the results for comparison and validation of MODIS derived landscape scale products. We propose to evaluate refinements to the SVIs, (e.g., applying recently developed atmospheric correction methods to the imagery, Ouaidrari and Vermote 1999), spectral unmixing to remove the soils spectral component prior to calculating appropriate SVIs).

Microbiotic crusts (Cross, Pregenzer, Shore, Kidron, Betancourt): Characterization and mapping the spatial distribution of crusts will be initiated with the aid of near-ground level spectral and optical analysis, and remote sensing (ADAR, AVIRIS). This requires developing spectral and/or optical signals for crusts. Correlations will be made with soil type, vegetation, soil chemistry, and other physical conditions. These data and remote sensing will be the basis for scaling to larger landscapes. To distinguish between physical and biochemical mechanisms, experiments will be performed on plots with crusts, with crusts removed, and with crusts replaced by physical simulants, such as appropriately sized rocks or inert mucilaginous material. We will calculate N-fixation rates using the Δ ^{15}N method (Shearer & Kohl 1986). We will use ^{15}N to examine denitirification, nitrification, immobilization rates under experimentally wet and drought conditions as well as use ^{15}N to examine dust deposition and water/wind erosion. The ^{15}N tracer will be applied to small plots with the three treatments described above to track ^{15}N partitioning within the microbiotic crust, plants, soil solution, mycorrhizae, and fine roots. The role of microbiotic crusts on other nutrients also will be studied. We also will remove microbiotic crusts in field settings and measure plant response (e.g., N, P, C content, biomass, seed set) in a manner similar to our other species removal experiments. Plant response with crusts replaced by physical simulants will also be measured.

Spatial pattern (Shore, Francis, Bader, Milne, Li): We are investigating changes in the distribution of woody species using high resolution, digitized, aerial photos and 1m resolution ADAR imagery (**fig. II.16**). Aerial photo and ADAR frames were classified as woody species, soil, and grass using minimum distance classification techniques and exported to GIS layers. We will also analyze patch distribution, geometry and size in the shrublands, grasslands and the transitions between them in order to relate structure to modification of microsite conditions.

Clonal studies (Lowrey): Fifty to sixty *Larrea* individuals from each of 10 different sampling sites will be tagged and mapped to study the clonal structure. Freshly collected leaf samples will be extracted in a Spruce Grinding buffer and stored in a -70 degree C freezer until subject to electrophoresis. Standard measures of allozyme diversity will be calculated within and

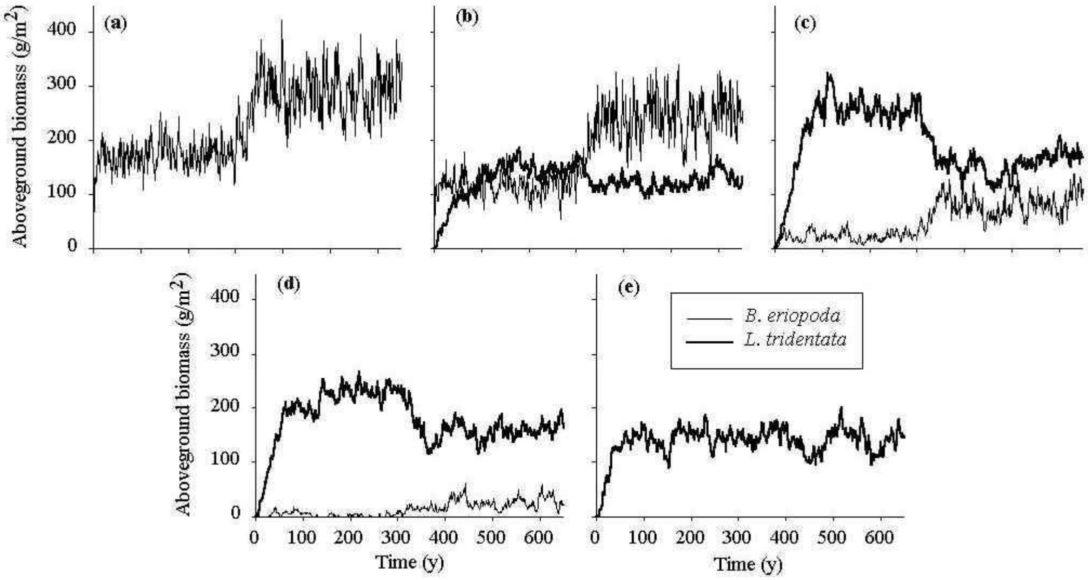
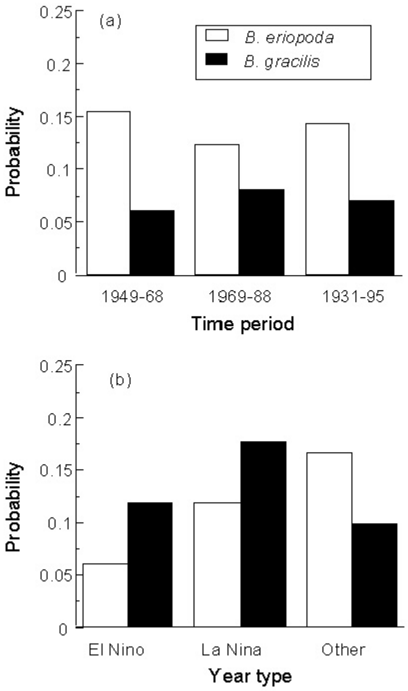


Figure II.17. (upper) ECOTONE simulation results for: (a) sandy loam, (b) degraded sandy loam, (c) gravelly loam, (d) degraded gravelly loam, and (e) very gravelly sandy loam. Climate change was imposed over a 50-year period beginning 300 years after initialization. Model runs were conducted that incorporated feedbacks from plant production to soil organic matter and plant available water that influenced seedling establishment (Peters & Herrick submitted). (lower) Simulated probability of establishment of B. gracilis (blue grama) and B. eriopoda (black grama) using weather generated from (a) one of three time periods (1949-1968, 1969-1988, 1931-1995) and from (b) one of three types of years (El Nino, Las Nina, Other, Peters in press).



among populations. Multilocus genotype diversity (DG) has been applied to clonal plant populations (Ellstrand and Roose, 1987) and will be calculated as a modification of the Simpson index for finite populations (Pielou, 1969). To infer spatial distribution of clones within populations, the proportions of individuals sharing the same multilocus genotype will be graphed against distance. Relationships with distance will be tested statistically by comparing distances between identical and nonidentical genotypes. Observed multilocus genotype frequencies will be compared to expected frequencies under the assumptions of Hardy-Weinberg equilibrium and random recombination using Chi-squared tests on the most frequent expected genotypes in each site sampled. These genetic studies will help address the paucity of data on ecological and genetic studies for a species at its border (Hoffman & Blows 1994).

Seed production/seed bank (Peters, Lightfoot, Gosz, Zlotin): The phenological stage of all plant species on will be recorded on a monthly basis on permanent 200 m by 1 m wide transect lines at each of the five core sites. All seeds will be counted from randomly selected individuals of each plant species with mature fruit.

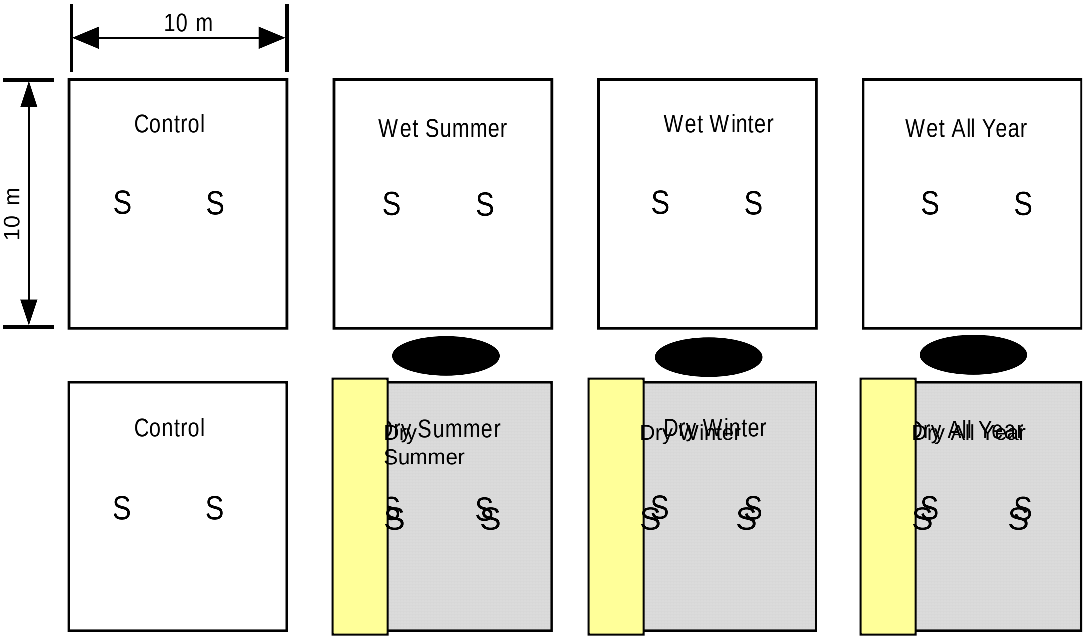
We also must evaluate the influence of seed viability and dispersal on the seed bank. We have initiated an annual seed bank study at three areas on the *Larrea* and grassland transitions. Fifteen soil samples to a depth of 10 cm will be collected randomly from a 15 m diameter area from replicate patch types of each area that represent dominant species and equal mixtures for 2 dominant species for a total of 405 soil samples (i.e., Blue Grama, Black Grama, *Larrea*, all pairwise combinations of each). Species germination from soil samples will be monitored in germination trays in the SEV lathe house.

Our core study sites in Juniper savanna and PJ will be used to monitor the long-term patterns of seed production in the woodlands to relate to the dynamics of climate and ecophysiology of the dominant species (Juniper, Piñon Pine, Oak). We will evaluate seed quality (well-developed/underdeveloped, undamaged/damaged by insects), seedling establishment, population levels of important seed-eating insects, and population levels of granivorous rodents in our sites to develop the models for recruitment success.

Establishment (Gosz, Pregenzer, Cross, Peters, Betancourt, Swetnam, R. Pendleton, B. Pendleton): We will evaluate establishment rates with respect to facilitation (i.e., nurse plant effect), scatter hoarding by fauna, seeds in fecal material and the role of soil moisture. A common design will be implemented that involves these factors at each of the study sites. We will test the simulation analyses (Peters, in press; **fig. II.17**) using field experiments to determine the effects of precipitation, temperature, and soil texture on seedling establishment. We will also conduct experiments on seedling establishment by *Larrea* since little is known about recruitment of this species in the Chihuahuan desert.

We will plant ten seedlings at each point; half will be protected with a metal screen cage, and the other half will be left unprotected, with an open-sided metal screen cage (to mimic microenvironment modifications of the complete screen cage). We will also attempt to document causes of mortality by noting herbivory, digging, etc. Facilitation will be tested under the canopies of dominant woody species and in the open using replicate plantings of ten single seeds and ten groups of 10 under wire cages with and without openings allowing rodent entry. Another set of the same design will receive a doubling of annual precipitation. Fecal material collected from other surveys will be used in a similar design. We will test germination rates of different grass and forb species in microbiotic crusts and with crusts replaced by crust simulants. Seeds will be placed in small holes in the crust (or simulant), protected from granivores with wire cages and monitored for rate of germination, survival and

Figure II.18. Plan-view of proposed experimental precipitation manipulation plots. Each plot is 10x10m. The text on each plot describes the precipitation treatment. Shaded plots include rainout shelters, to replicate drought conditions during summer, winter, and throughout the year. Precipitation will be limited to the minimum observed values (seasonal or annual) from nearby long-term records. The black ovals represent storage tanks for water to be redistributed from Dry to Wet plots. Rainout shelters will be on tracks to allow movement on and off of the plots during anticipated wet and dry intervals, respectively. Two control plots that receive only natural precipitation will also be monitored. Precipitation will be applied to the wet plots at the observed intensity. "S" designates location of permanent vertical soil moisture (TDR and neutron access tubes) and soil temperature profiles. Each plot will be isolated from the surrounding areas by trenching, inserting metal sheets to a depth of ~2 m, and back filling the trenches. A weather station will record precipitation, wind speed, temperature, humidity, and solar radiation at the site. A variety of plant (physiological and ecological) and hydrologic properties will be monitored, including species composition, NPP, root distribution, fractional vegetation cover, the surface radiation balance, soil moisture and temperature, infiltration capacity and runoff. Plots will have raised walkways that can be positioned to perform analyses when needed and removed to avoid walking on plots or shading plants.



N levels relative to control seedlings. All experimentally and naturally established seedlings in our intensive study areas will be permanently marked and located to allow annual assessment of their populations.

Species removal/mortality experiments (Peters, Pockman, Allen, Gosz, Small)**:** In 1995, the dominant individuals of species (Blue Grama, Black Grama or *Larrea*) were removed from within 3 m x 4 m plots with minimal soil disturbance. Plots have been maintained through time by removing new individuals of the appropriate dominant species. Cover and density by species are estimated annually for all plots at peak standing crop (mid-September). Erosion bridges were installed at a subset of plots to evaluate effects of dominant species cover on surface soil loss. For these individual plant mortality studies, we are creating plant death as well as monitoring natural plant mortality. In 1999, we initiated a long-term study of vegetation dynamics after individual shrub mortality. We will test the hypothesis by killing a sequential number of individuals of each species in communities where they dominate. Patches of plant mortality will be created by killing one plant, two adjacent plants, three adjacent plants of the same species until an area similar in size to the removal plots (3 m x 4 m) is reached.

Freezing- or drought-induced xylem cavitation, by eliminating water transport, can cause mortality and shift species distribution (Pockman & Sperry 1997, Pockman & Sperry 2000). We will evaluate the role of cavitation on seedling and adult mortality for dominant species in the transitions. Seasonal measurements of predawn and midday water potential, xylem embolism (Sperry et al. 1988), leaf area and growth of dominant woody species and grasses, combined with climate data, will test our hypotheses. Heat balance (Steinberg et al. 1990) and constant heat (Granier 1985, Granier 1987) sap flux methods will be used to measure whole plant water loss for comparison with water relations and xylem embolism measurements above. Leaf gas exchange (Pearcy et al. 1989) will determine water use by seedlings at the same intervals as water relations measurements. Seed germination and seedling establishment will be monitored and water status and xylem function will be related to mortality (Kavanagh and Zaerr 1997, Williams et al. 1997).

In a collaborative effort with scientists from New Mexico Tech and the new Hydrology Science and Technology Center, we will construct "rainout" shelters to impose drought stress on species in the *Larrea*-grassland transitions. The design will be a series of 10 m x 10 m shelters (**fig. II.18**) that divert precipitation from sheltered plots to storage tanks. The shelters will be on tracks to allow moving onto plots when precipitation is expected. Collected water will be applied to adjacent plots to test increased moisture effects. This scale is sufficient for measurements of plant gas exchange and water relations, nondestructive measures of plant volume (NPP), root minirhizitron studies of root turnover and mycorrhizae, and detailed water/energy flux measurements.

Organic matter/N dynamics (Gosz, Craig, Cross, Peters): The decomposition study includes annual collection of leaf litter of primary species and placement in all intensive research sites (Feb.) in mesh bags that are retrieved periodically over a 2-year period. We will continue N mineralization and nitrification studies at all sites to understand factors contributing to N availability (e.g., drought, ppt.) and plant uptake.

Mammals (Parmenter, Lightfoot, Friggens): Our studies will address site-specific and landscape-level spatio-temporal dynamics of mammal populations, and will develop multi-species energy budget models to assess herbivory impacts on ANPP. Metabolic demands for energy by all resident terrestrial mammal species will be calculated using estimates of species-specific physiological energetic costs for various activities (foraging, resting, dispersal;

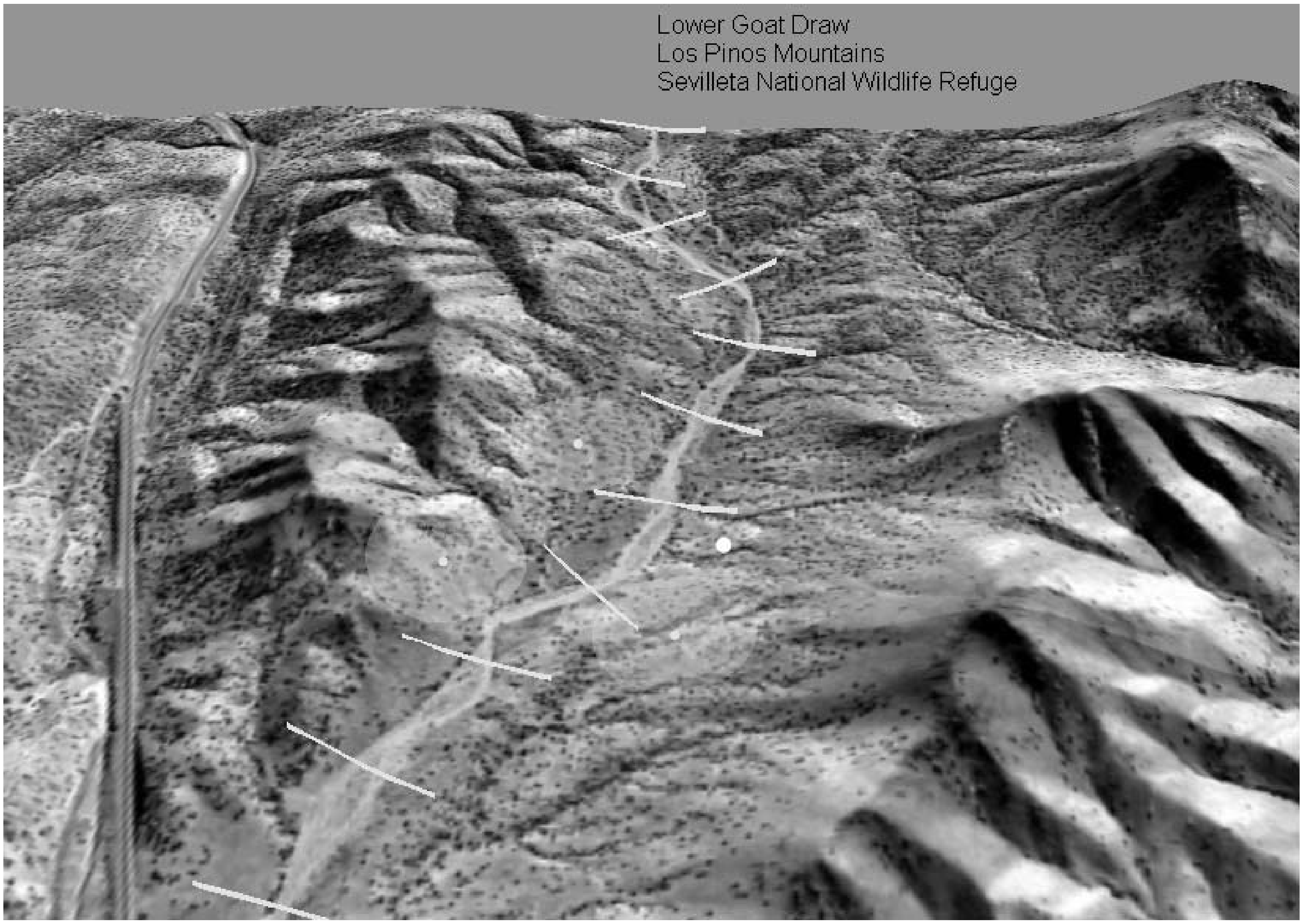


Figure II.19. The transition being studied from the Juniper savanna to Piñon-Juniper forest occurs in a drainage system referred to as Lower Goat Draw (in the SEV's Los Pinos Mountains). The ADAR image above shows 11 of the 35 rodent trapping lines (yellow lines) arranged along a ~7 km transect from grassland (off image in foreground) to the PJ study site (beyond horizon in background). LTER permanent trapping webs and NPP plots for the Juniper savanna study site are shown as yellow circles; meteorology station is the white dot in center. A replicate ~10 km transect will be located in the southern Los Pinos Mts. in Montosa Draw. The 200 meter, 20 station trap lines extend across the main arroyo into upland grass/wooded areas; preliminary results from our rodent-hantavirus studies indicate that rodents extensively use arroyo bottoms for long-distance movements. Hence, dispersal studies (augmented with radio telemetry and night-vision studies) within these large-scale transition zones will detect movements and changes in abundances of each species across habitats, allowing us to understand processes and constraints on dispersal and inter-habitat movements. These data will then be integrated with the NPP/herbivory/seed dispersal studies and the predator-prey interactions studies.

Parmenter et al. 1984, Tomasi & Horton 1992, Porter et al. 1994, Nagy et al. 1999). These values will be integrated with species-specific density estimates to compute an overall energy demand on a daily or seasonal basis. Diet studies of rodents (Hope & Parmenter submitted) and coyotes (Herandez et al. submitted) will be used in constructing actual food resource lists and caloric equivalents. Activity patterns (active periods and local movements) of individual small mammals will be measured using radio telemetry techniques and night-vision equipment using standard techniques. Continuous burrow temperatures will be measured with thermocouples hooked to data loggers. These data will be incorporated into the energy models with literature values on physiological processes and LTER site-data on microclimate.

Density estimates of mammal populations will be compiled from our continued field studies on small mammals (rodents, rabbits) coyotes. These studies will include: 1) mark-recapture studies of rodents on 3 replicate trapping webs in each of the five core study sites during mid-winter, late spring, and late summer seasons; 2) seasonal nocturnal spotlight sampling of grassland/desert rabbit population densities; and 3) seasonal scat count samples for coyote population densities. We will establish new predator scent post transects to determine relative abundances through time and across sites of other (non-coyote) predators known to be in the area (cougar, bobcat, gray fox, kit fox, badger). The Sevilleta Fish and Wildlife Service staff will initiate monthly aerial surveillance samples for native ungulates (antelope, deer), and large predators (mountain lion, bear).

To evaluate the role of landscape movements and dispersal in driving the population dynamics of rodents, we will initiate a study that will measure individual rodent movements along two transects of 7-10 km in the Juniper savanna to PJ transition (**fig. 19**). Each transect will consist of 200 m, 20 live trap station lines running perpendicular from the main transect line spaced at 200 m intervals. Traps will be run seasonally, but more frequently during rodent population outbreaks. Additional radio telemetry studies and night-vision observations will complement the trapping studies to ascertain the extent of individual movements, i.e., the "ebb and flow" of rodent populations across the large habitat gradients. Similar transects will be established across the *Larrea*-grassland transition. The resultant dynamics will be correlated with predator abundances (“top down” controls), food resource abundance (“bottom up” controls) and climate conditions (“abiotic” controls).

Birds (Parmenter, Waide, Friggens, Finch, Stoleson, Kelly): Birds will be surveyed on all intensive study areas for effects of intra and interannual patterns with climate, fire, and grazing. Density estimates will allow energetics models for effects of granivory and seed dispersal. Particular species will be surveyed for reproductive success in native and transition habitats.

Arthropods (Lightfoot, Pamenter, Friggens): Our proposed arthropod studies will focus on ground-dwelling arthropods, plant-dwelling arthropods, and grasshoppers. We will monitor ground-dwelling arthropods and grasshoppers at the existing core study sites and will initiate studies of plant-dwelling arthropods at and between the core study sites. We will install pitfall traps and grasshopper transects at all core sites and across transitions at the same locations that we select to monitor plants for ANPP and phenology. We will sample plant-dwelling arthropods from the same plants that are tagged for ANPP and phenology measurements.

Herbivory (Lightfoot, Zlotin, Peters): Our goals are to determine consumption rates and the effects herbivores have on plant species distribution and abundance. Diets and consumption rates of herbivores will be assessed for time of day and season. Depending on the species of

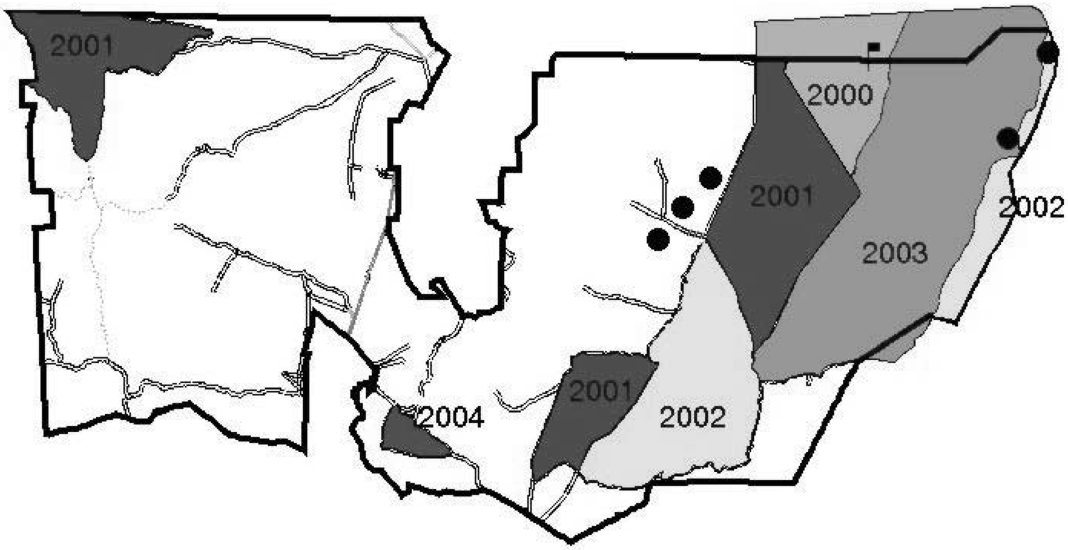


Figure 20. The U.S. Fish and Wildlife Service will initiate prescribed burning management for various sections of the Sevilleta Refuge starting in May, 2000. The various areas and times designated for burning are color-coded. The black dots identify our intensive research sites. The intensive research sites in the *Larrea*-grassland and Blue Grama-Black Grama transitions (uncolored) will not be burned and will provide a control for evaluation of the effects of fire management. The intensive sites in Juniper savanna and PJ (green) will be protected from the burning that will take place throughout the area in 2003. Other ground-based monitoring, aircraft, and satellite imagery will evaluate effects of burning management on C_3 woody species presence.

herbivores, nonlethal methods of stomach analysis will be preferentially utilized (vertebrates) rather than dissections (insects). Fecal analysis will also be used to identify plant fragments in the diets of rodents and rabbits. We will use field observations to develop foraging time budgets for the various herbivores on different plant species at different locations. A series of replicate, screened exclosure cages of various sizes will be used to monitor herbivory on particular plant species. Each caged plant will be paired with an adjacent control individual of the same plant species with similar morphology. Open-sided cages will be placed over control plants to simulate any abiotic effects that the exclosure cages may have on the plant's microenvironments.

Prairie dogs/K-rats (Lightfoot, Parmenter, Peters, Friggens, Waide): Our study site is located near the north boundary of the SEV where a Gunnison's prairie dog colony has recently moved onto the refuge from private rangelands to the north (ca. 1998) and is continuing to expand southward into the refuge. Three contiguous sampling grids have been established: one located within the present colony, one located in the area south of the colony where no prairie dogs are present (the control plot), and one located in the transition area between the colony and control plot, which is partially occupied by prairie dogs. Vegetation, ground-dwelling arthropods, and lizards are also sampled around selected K-rat and prairie dog mounds. K-rat and prairie dog mounds are mapped and monitored to determine the expansion of the colony through time and how the expansion of prairie dogs is influencing the resident kangaroo rats. Vegetation is sampled at the local mound scale and at the study plot scale.

Annual, low-level aerial photography (15 cm resolution) will document changes in vegetation and bare soil as the colony expands. Soil disturbance is measured on the same quadrats when vegetation is measured. Grasshoppers and lizards are counted along the transect lines associated with the Prairie dog and K-rat mounds, non-mounds, and plot grid lines.

Ground dwelling arthropods will be sampled to compare assemblages within prairie dog and K-rat burrows. Arthropods will be extracted from 20 prairie dog and 20 K-rat burrows using a modified D-vac (a gasoline-powered, portable vacuum-like device used to sample insects from plant foliage). Ground-dwelling arthropods also will be sampled at the landscape or study plot scale using the grid matrices to locate pitfall traps. Other rodent species are monitored on the colony, transition area, and control site by live trapping using established techniques. We will plant *Larrea* seeds and seedlings at a series of points throughout the Gunnison's prairie dog town to test the hypothesis that prairie dogs prevent shrub invasion.

II.4.C. Fire Studies (Parmenter, Gosz, Muldavin, Peters, Lightfoot, Friggens, Ford, R. Pendleton, B. Pendleton): Prescribed burning management (**fig. II.20**) will be initiated by Fish and Wildlife Service personnel in 2000 and coordinated with our research efforts. High resolution, near-infrared, false-color aerial photos will be collected prior to and immediately following each prescribed burn. The aircraft imagery will document the mosaic pattern created by fire (i.e., burn/unburned patches) as we expect the fire to burn ~ 60% of an area. Spectral unmixing of low altitude AVIRIS, available prior to the fire, will provide fractions of green vegetation, litter and soil for each pixel which can be correlated with community type from the aerial photos. These correlations will provide the basis for estimating fuel loads per community type in order to model fire behavior. Future burns will provide validation for the model. Our line intercept measurements for vegetation change on previous natural burns from 1990 to 1998 will be repeated during the years following management burning to evaluate how subsequent burns affect vegetation change compared to the previous burn. We will collaborate

Table II.1. Sevilleta Remote Sensing Imagery

Sensor	IFOV	Bands	Spectral Range	Temporal Resolution	Applications
ADAR	1 m	4	0.40 – 1.00 µm	Jan 1998	Environ. monitoring Vegetation mapping Agriculture
Aerial Photos	Varies	1-3	Varies	1935 – 1998 Available from various agencies	Community composition Spatial patterns Change detection
AVHRR	1.1 Km	5	0.58 – 12.50 µm	Biweekly 1989 – 1999	Vegetation monitoring Cloud & surface mapping Sea surface temp. Snow & ice extent
AVIRIS	20 m	224	0.38 – 2.50 µm	2 /year 1997 - 1999	Vegetation Geology Hydrology Fire
Digital Video Imagery	Varies	3	0.55 – 0.86 µm	2/year 1997 - 1999	Vegetation monitoring Community composition Spatial patterns
MASTER	50 m	50	0.4 – 13.0 µm	Jun 1999 Sep 1999	Surface climate Atmosphere Vegetation Ecosystem dynamics
MSS	68 m	4	0.50 – 1.10 µm	May 1974 Dec 1975 Sep 1977	Vegetation monitoring Water land interface
Radar					Terrain mapping
AIRSAR	8.0 m	P-Band	40.00 – 76.90 cm	1993	Ocean waves
ERS-1	12.5 m	C-band	6.00 cm	1994	Ice sheets
JERS–1	18.0 m	L-band	24.00 cm	1994	Subsurface features
IFSAR	2.5 m	X-band	2.75 – 5.77 cm	1999	
SPOT	10 m	1	0.51 – 0.73 µm	Jun 1991 Sep 1991	Terrain mapping Feature mapping PAN Sharpening
TIMS	~ 7 m	6	8.20 – 12.20 µm	Jun 1997 Sep 1997	Mineral mapping
TM	30 m	7	0.45 – 12.50 µm	1-4 /year 1984 - 1999	Vegetation monitoring Vegetation & soil moisture Thermal mapping
TMS	~ 7 m	12	0.42 – 14.00 µm	Jun 1997 Sep 1997	Thematic mapper simulator

our efforts with Forest Service studies that will evaluate shrub reproductive responses to fire and effects on mycorrhizal relationships.

II.5. Synthesis and Extrapolation

II.5.A. Modeling (Peters, Martens, Breshears, Milne, Li, Small, Hendrickx,): We use simulation modeling in three ways: 1) to generate hypotheses that can be tested using experiments; 2) to synthesize results from experiments and monitoring efforts with the literature to determine gaps in our knowledge and to identify key processes affecting transition dynamics; and 3) to make predictions as to the future dynamics of transitions. Our approach to simulating vegetation dynamics in the *Larrea*-grass transitions is to use an individual plant-based simulation model (ECOTONE). The hypotheses generated by these model results will be tested by the experiments on seeds and seedling establishment. This work will be coordinated with a similar modeling effort at the Jornada.

Our future modeling plans include adding competition for nitrogen and light into ECOTONE. We recently integrated the 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. We also plan on expanding our modeling efforts to other transition zones at the SEV. Under separate funding (COMPBIO project), 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 expand on this version of ECOTONE to simulate interactions among patch and ecosystem types found throughout SEV. To do this, we plan to link the ECOTONE model of vegetation dynamics with the SPLASH model of soil water balance. We also plan to collaborate with Dave Breshears at Los Alamos Laboratories to modify the structure of ECOTONE for PJ ecosystems and juniper savannas found at the core sites. In addition to SPLASH, other hydrologic modeling efforts will be incorporated to synthesize and simulate water/energy fluxes (i.e., SABLE, Biosphere-Atmosphere Transfer Scheme (BATS).

SPLASH will be modified to use the soil hydraulic parameters determined for SEV soils, and to use the new, detailed soils map to improve our ability to simulate landscape hydrologic conditions at SEV. SPLASH simulations at 30 m resolution for all of SEV will be run, processed, and visualized in collaboration with the San Diego Supercomputer Center. New SPLASH development will include the use of NEXRAD precipitation data, and simulation of primary productivity to complement ground measurements and remotely sensed estimates (i.e., MODIS).

Finally, we will utilize energetic models to incorporate the role of fauna in the processes that affect vegetation changes. Process models will be integrated with the spatially explicit models from SPLASH, ECOTONE, scale-dependent, scale–invariant, fire, and remote sensing efforts.

II.5.B. Remote sensing (RS) studies (Wessman, Bader, Vande Castle, Shore**,** Harrison, Francis, Morain, Vanderbilt, Milne, Hendrickx)**:** We have a growing collection of RS imagery covering multiple spatial, spectral and temporal scales (**table 1**). Future acquisitions will include: aerial photography bracketing burn dates; monthly Landsat 7 thematic mapper throughout the growing season; biannual AVIRIS, MASTER, and digital video imagery; biweekly composited AVHRR; and, Aster and MODIS data including derived products from the Terra satellite. In addition, there exists a comprehensive suite of ancillary data including IFSAR derived digital elevation maps (10 m resolution), multiple GIS layers, published and field acquired spectral libraries, and TRMM imagery for rainfall. This extensive set of RS data

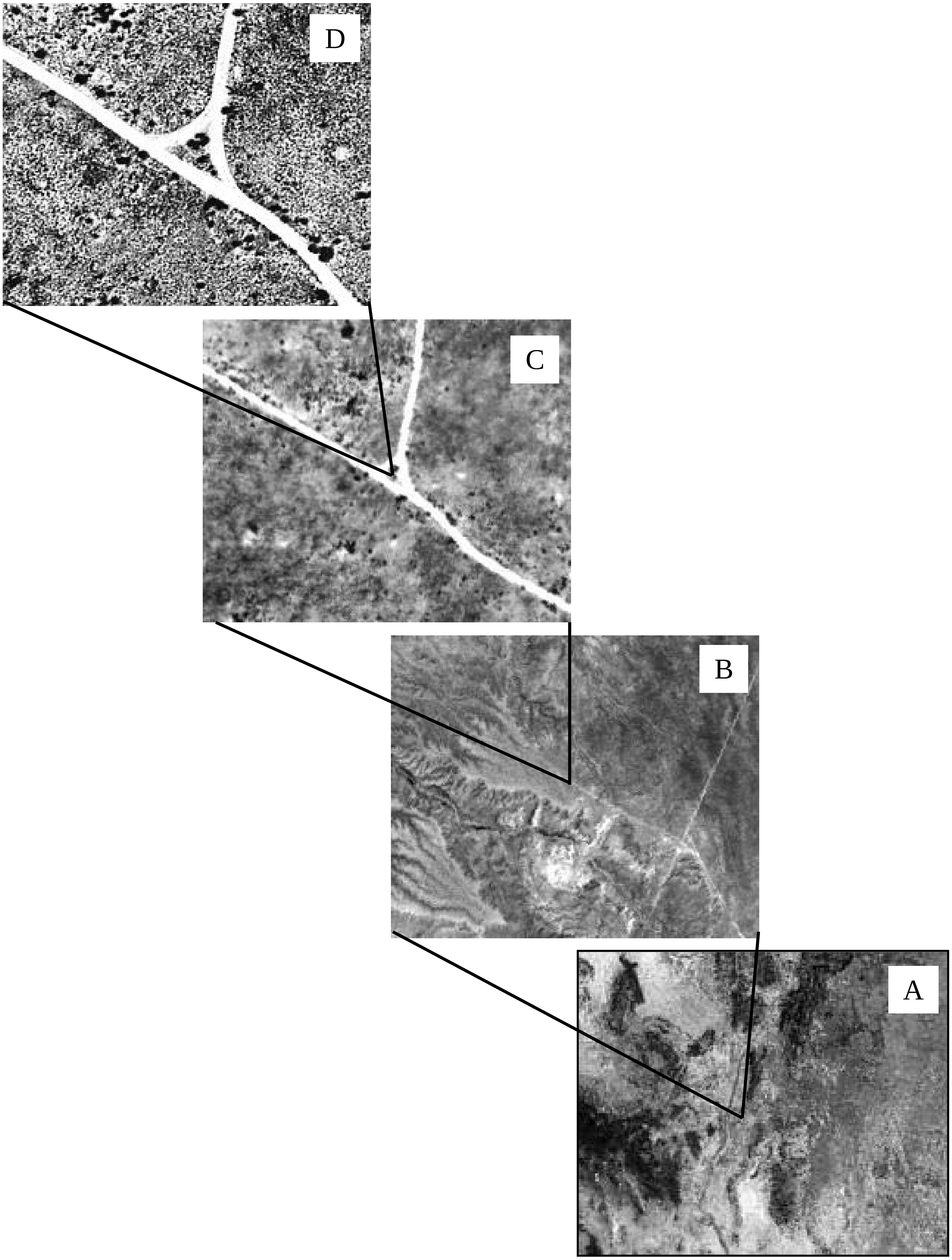


Figure II.21. A comparison of image resolution for remote-sensing imagery within the Sevilleta LTER archive: A) 1 km AVHRR (bands 2, 1, 3); B) 30 m TM (bands 4, 2, 1); C) 1 m ADAR (bands 4, 2, 1); and D) 16 cm Aerial Photo (CIR).

allows us to conduct ecological studies at various spatial and temporal scales (**fig**. **II. 21**) and investigate different RS techniques across scales. For example, the exclosure plots on rangeland neighboring SEV present an opportunity to study the effects of landuse on ecosystem properties inside and outside of SEV. We propose to study 9, 300 m x 300 m plots that represent grasslands where cattle have been excluded for 6 and 27 years. Initially, we will focus on AVIRIS imagery acquired over SEV in 1997, 1998, and 1999. These years encapsulate relatively extreme climatic conditions associated with ENSO and will illuminate interactions between climate and rangeland recovery from grazing and best demonstrate interannual variability for ecosystem processes. Spectral mixture analysis (Asner et al. 1998, Bateson and Curtiss 1996, Bateson et al. In press, Wessman et al. 1997) of the AVIRIS images will identify the distribution of landscape components such as soil cover and green vs. dead vegetation and allow us to track the effects of climate and landuse on landscape structure.

In concert with the focus on landuse, we will use the AVIRIS, TM and AVHRR archives and newly available MODIS data to look at ecotone dynamics associated with interannual variability in climate. Using spectral mixture analysis, we can quantify the abundance of landscape components of structural significance to ecotone dynamics such as herbaceous-to-woody ratios, patchiness, and connectivity. Cross-site comparisons with the Jornada LTER will be used to further expand on climate-grazing interactions.

In conjunction with the Department of Electrical Engineering/Computer Engineering, we will develop innovative computational methods and software for applying high-performance computing to fundamental problems arising in the analysis of remotely sensed image data. This work will be conducted jointly with the Albuquerque High Performance Computing Center (affiliated with NCSA Alliance/UIUC). The aim is to build a family of software modules that make use of different algorithms to: 1) carry out reflectance correction of images (e.g. illumination gradients caused by non-uniform viewing angles); 2) accurately co-register remote-sensing imagery produced from different sensors and spatio-temporal resolutions, to eliminate signals from extraneous sources (e.g. atmospheric correction) 3) generate derived geophysical properties; and 4) identify species reflectance signals. Our applications development will be conducted on high-performance computing platforms at The University of New Mexico; a 128-processor Linux SuperCluster with Myrinet, a 128-processor IBM SP-2, and an IBM Netfinity cluster consisting of 32 Intel Pentium III processors networked via an IBM high-performance switch. The UNM high-performance computing facility has approximately one Terabyte of online disk storage and tertiary storage system.

II.6. Cross-site Studies

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 than currently found at the SEV. Most of our comparisons focus on a north-south regional gradient that extends from the northern limits of the Shortgrass Steppe in Colorado (SGS LTER) to PJ woodlands of Los Alamos in northern New Mexico, and Chihuahuan Desert in southern NM (JRN LTER) and Mexico (Mapimi). These sites for experimentation and monitoring are augmented with remote sensing, simulation modeling, and GIS allowing us to extend our results to the region. A number of our studies have comparable efforts and methods at the Short Grass Steppe LTER (SGS), Jornada (JRN) LTER and Mapimi. Comparisons also are being made in grassland systems in Hungary (Gosz et al. 2000) and desert systems in Israel. Space limitations require us to list the topics that are involved in these comparisons (**table 2**).

Table II.2. Cross-site Collaborations				
TITLE	SITES	PIs	Collaborators	Funding
Effects of indigenous small mammals on species composition and structure of Chihuahuan Desert communities	SEV/JRN/Mapimi, Mexico	Lightfoot Hernandez	L. Hernandez	NSF/LTER/CONCyT
Relationships between climate change and topography on ground-dwelling arthropods in the Southwest	SEV/JRN/Bandelier National Monument/Los Alamos National Lab	Lightfoot Brantely	C. Allen, T. Harrmann, R. Fagerlund	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 Military Reservation /White Sands Missile Range	Lightfoot Huenneke	L.F. Huenneke (JRN-LTER)	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, Gosz	L.F. Huenneke (JRN-LTER)	NSF/LTER
Long-term ANPP monitoring	SEV/JRN	Gosz, Lightfoot Huenneke	L.F. Huenneke (JRN-LTER)	NSF/LTER
Effects of fire, grazing, and small mammals on vegetation, grasshoppers, rodents, lizards, and birds	SEV/JRN	Gosz, Lightfoot, Peters	K. Havstad (JRN-LTER)	NSF/LTER, BLM, ARS
Patterns in biodiversity across spatial scales	SEV/JRN/SGS/3 sites in Hungary	Peters, Gosz	E. Kovacs Lang (HAS) Sandor Bartha (HAS)	NSF/INT
Simulated effects of climate change on semiarid grasslands	SEV/JRN/SGS/3 sites in Hungary	Peters, Gosz	E. Kovacs Lang (HAS) Sandor Bartha (HAS)	NSF/INT
Vegetation-soil feedbacks and response of grasslands and shrublands to climate change	SEV/JRN	Peters	J. E. Herrick (JRN-LTER)	NSF/LTER, ARS
Biosphere-atmosphere interactions and shifts between grasslands and shrublands	SEV/JRN	Peters	R. Pielke (SGS-LTER), J. Eastman (CSU), J.E. Herrick (JRN-LTER)	ARS
JORNEX project (remotely sensed data on biological and physical properties of arid ecosystems)	SEV/JRN	Gosz	A. Rango (JRN-LTER), J. Ritchie (ARS)	ARS, NSF/LTER
Microbiotic crusts and arid ecosystems	SEV/JRN/Negev Desert, Israel	Cross, Pregenzer	G. Kidron (Israel)	NSF/LTER, Mitrani Center

Table II.2 continued				
Variation in precipitation, plant production, and grasshopper population dynamics	SEV, JRN, Mapimi, Mexico	Lightfoot		NSF/LTER
Effects of indigenous small mammals on the species composition and structure of Chihuahuan Desert communities	SEV, JRN, Mapimi, Mexico	Lightfoot		NSF/LTER
Relationships between climate change and topography on ground-dwelling arthropods in the Southwest	SEV, JRN, Bandelier Natl. Mon., Los Alamos	Lightfoot		NSF/LTER, USGS/BRD, DOE
The response of grasshopper assemblages to variation in precipitation and plant production in the northern Chihuahuan Desert	SEV, JRN, Mapimi	Lightfoot	E. Rivera	NSF/LTER
Effects of domestic livestock grazing and climate change on vegetation and grasshoppers in New Mexico semi-arid grasslands	SEV, Bosque del Apache NWR, Fort Bliss Military Res., White Sands Missile Range	Lightfoot Huenneke	M. Bogan	USGS/BRD
Factors regulating below-ground carbon allocation in terrestrial ecosystems: A cross-site experiment	SEV, many other sites	Allen, Pregitzer, Ruess, Hendrick		NSF
Harbingers of anthropogenic ecosystem stress: mycorrhizal fungi and weedy plants	SEV, many other sites	Michael Allen, Edith Allen, Clifford Dahm		EPA
Mycorrhizal responses to nitrogen eutrophication at five mesic to semiarid sites	SEV; 4 other sites	Edith Allen, Nancy Collins Johnson, Michael Allen		NSF/LTER
Quantifying grassland-to-woodland transitions and the implications for carbon and nitrogen dynamics	SEV, Jornada, Texas	C. Wessman, G. Asner, S. Archer		NASA

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IV. Site Management

This proposal is the result of 2 years of deliberation following our site review in 1997. It reflects a reorganization of effort, reduction in scope in terms of areas on the Sevilleta that were involved in previous LTER efforts, but intensification of integrative efforts on the key areas that formed the initial Sevilleta theme – biome transition areas. The renewed focus on the science of these transitions also required additional expertise that we have solicited from new PIs at other universities. We also have developed more interactions and collaborations with agency scientists; U.S. Fish and Wildlife Service, U.S.F.S. Experiment Station (Albuquerque), ARS Jornada Experimental Range, U.S.D.A. Laboratory, Beltsville, MD, USGS (Tucson), NASA, and Bureau of Reclamation. This broadened and more complex set of collaborations requires more organized efforts at communication and clear channels of responsibility. **Figure IV.1** is a schematic of interactions of the principal individuals and groups in the Sevilleta management plan. A. More PIs at other universities and agency scientists requires designation of two individuals that provide the contacts for the Sevilleta program. People outside UNM need a primary contact to obtain information, request assistance, logistical details (e.g., field station lodging, vehicles), and field technician help. Gosz and Parmenter serve this role. They also are responsible for passing information to the broader Sevilleta community. There will be information flow among all PIs regarding scientific results, discussions of new research topics, etc. Gosz, Parmenter, and the Administrative Assistant will manage finances, schedule activities, and field station operations.

B. All staff members have clear responsibilities developed in the research plan. The PI (Gosz) is responsible for scheduling the activities of staff for physical measurements (Moore), remote sensing/GIS (Shore), and analytical laboratory management & analyses (Craig). This chain of command is required to reduce demands on the staff time for work that may not have been scheduled. PIs that need work performed by these staff request this assistance through Gosz and Parmenter.

C. Field staff are under the supervision of Parmenter and Lightfoot for the same reasons as outlined in B.

D., E. The immediate supervisors for technicians in the analytical laboratory (Craig) and field crew (Friggens) manage the time and activities of permanent and student technicians.

F., G. Samples and voucher specimens collected in the research program will be archived in the Museum of Southwestern Biology. Physical samples (e.g., soil, water, plant tissues) will be archived under the direction of the Laboratory Manager (Craig) and invertebrate and vertebrate specimens under the direction of the Field Crew Leader (Friggens). All voucher specimens and associated nomenclature will be verified under the direction of taxonomic experts in the Museum of SW Biology. Physical samples will be archived by established protocols (e.g., LTER soils book ref.).

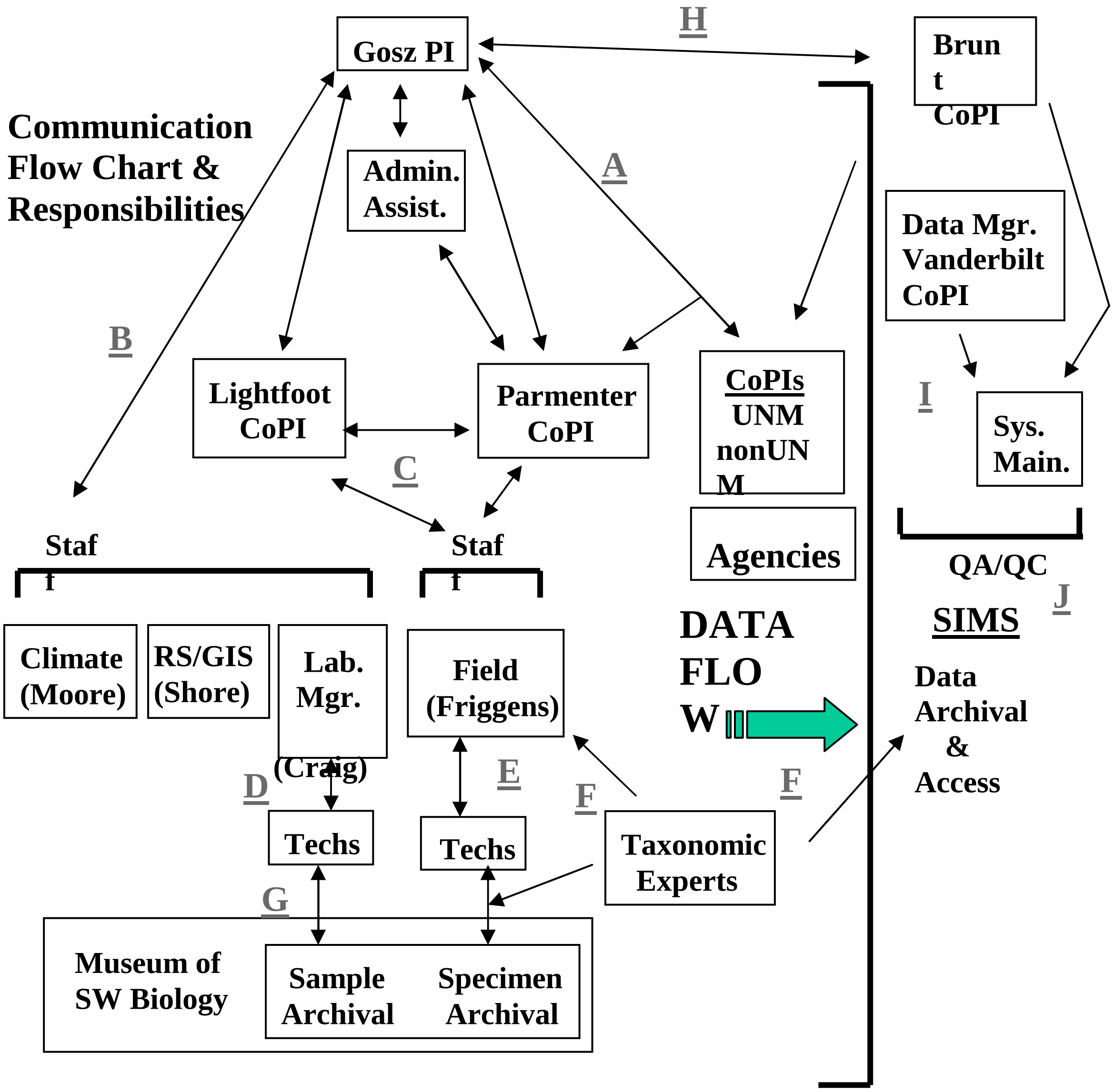
H. Data generated by laboratory analyses, field measurements of both staff and PIs are incorporated in the Sevilleta Information Management System (SIMS). All projects, analyses, and measurements have identified staff or PIs that are responsible for data entry and QA/QC into SIMS. The Sevilleta data managers (Brunt, Vanderbilt) are responsible for training of staff and PIs in appropriate QA/QC, metadata formats and SIMS management. Therefore they work closely with all PIs and staff generating data. The PI (Gosz) is responsible for ensuring that there are appropriate resources for SIMS and the communication of needs from Sevilleta PIs and the broader scientific community.

I. The data managers are supervisors for staff performing systems maintenance on SIMS computers and the network of PCs and workstations used by UNM scientists.

J. Data managers manage the overall design and maintenance of SIMS and requests for information from the broader community. They also maintain the Sevilleta web page and keep abreast of developments in information management that need to be communicated to the scientific community. The data managers also are responsible for interactions with the data management community in the LTER Network and participation in the LTER Network Information System.

Sevilleta meetings of UNM PIs and staff are held weekly to monthly during the academic year, opportunistically during the field season. Results are communicated to all Sevilleta PIs and associates. These meetings involve discussions of results, planning activities, and decisions on current or new projects. All projects developed by the PIs are subject to review and approval by the U.S. Fish and Wildlife Service that provides another level of security against inappropriate use or damage to previous studies.

Figure IV.1. Communication Flow Chart and Responsibilities.



V. Data Management for the Sevilleta LTER Project

The Sevilleta LTER project (Sevilleta) researchers have been dedicated to building a quality data management program from the very first Sevilleta proposal. This is evident in the number of staff resources that have significant data management components. This commitment made the Sevilleta an early leader in the area of ecological research data management. Protocols and procedures in use at the Sevilleta have been incorporated into the data management systems of other research projects including several LTER sites. For example, the Intersite Archive File (IAF; Conley and Brunt 1991) format was adopted and adapted for use at NWT, CPR, DOE research parks, Jones Ecological Research Center, and in the Chinese Ecological Research Network (CERN) among others (Wengui et al. 1994, Ingersoll et al. 1997). The Sevilleta data management process has been taught in training courses nationally and internationally and several components have been published in the peer-reviewed literature. Sevilleta data management personnel have also contributed to network and community efforts that have provided the groundwork for today's data access and data sharing efforts. Sevilleta III continues this commitment to data management, ensuring that data are of the highest quality and that their long-term stewardship is provided for, by having an informatics researcher (Kristin Vanderbilt) as Information Manager and PI. In addition, we will take several new steps to improving the data management system at Sevilleta by:

- Implementing a system for tracking the use and impact of Sevilleta data sets,
- Improving the management and discovery of Sevilleta data by implementing the current data set catalog in a web-accessible relational database,
- Improving the use and interoperability of Sevilleta data by implementing structured metadata following community standards,
- Improving our ability to manage and analyze large remotely-sensed data sets by collaborating on the research and development of terabyte-scale data systems,
- Designing or adopting a system of sample archiving to provide for the storage and management of soil, water and other samples,
- Improving the taxonomic integrity and registration of data through curated voucher specimens,
- Improving computing infrastructure for data management.

Each of these new areas of interest is developed for the reviewer below. The core Sevilleta Information Management System (SIMS) is documented in the published literature (Brunt 1994). And can be studied in greater detail at http://sevilleta.unm.edu/data/management/ .The activities of the Sevilleta data management personnel and the effectiveness of the SIMS are reviewed annually by the Investigators.

Tracking Sevilleta LTER data use - During Sevilleta I, data management personnel tracked the use of Sevilleta data by means of a software driven 'request handling procedure' – anyone receiving a 'data request' would fill out the information therein when providing inside or outside researchers with requested data. When the World Wide Web (WWW) became the data delivery method of choice, the Sevilleta program was one of the first LTER sites to embrace open data accessibility for all data sets. Data sets that had passed initial QA/QC screening were made openly available on the web starting in 1994 along with a suggested citation for users of the data. There have been, however, no restrictions to the access of these data. This open policy makes it very difficult to track the usage of data sets internal or external to the Sevilleta investigators. Simply counting the number of annual 'web hits' on a given data set (which number in the tens of thousands) does not provide accurate or useful information for tracking the use or impact of these data. **We will implement an automated system that tracks the use of Sevilleta data sets similar to the very short information requests that most online software provider's request prior to downloading software.** This system will be implemented using SQL Server relational database software and Perl 5 and Java script programming languages. Access information will become part of the information associated with each data set in the data catalog.

An Improved Metadata Catalog - The Sevilleta LTER maintains a very rich data catalog that contains information (metadata) about each data set. The catalog documents information about originators, sampling frequencies, status, etc. in a highly structured text file. This file is parsed by a number of sql-like operators. This method is functional for managing Sevilleta data sets but was developed long before the onset of the World Wide Web and the plethora of cross-platform tools and interfaces that have now come to be standard implementations. **We will convert our structured text catalog file to a fully relational database in SQL Server that can take advantage of these web-based tools to present and modify the information about Sevilleta data sets.** These improvements will make it easier to interface with network and community wide data and information discovery systems such as the LTER Data Table of Contents (DTOC), Global Change Master Directory (GCMD), and others.

Improved Data Delivery System through structuring metadata - Sevilleta data are currently extensively documented and each data file contains not only the data but also all the necessary metadata content for reuse of the data and re-sampling of the sites. These metadata are loosely structured following Conley and Brunt (1991). To be useful today, these metadata must be structured so that they can be parsed into machine readable and transferable formats. Community efforts in this area have resulted in the development of Ecological Metadata Language (EML) that uses eXtensible Markup Language (XML) to describe ecological metadata after Michener et al. (1997). A second generation of EML is under development that provides the necessary representation and semantics for producing machine-readable data sets. **The Sevilleta LTER program will collaborate in this effort to produce structured metadata that will make our data conform to community standards and easier to integrate with other ecological data sets.** In addition, these improvements will allow us to produce modular software tools that will allow Sevilleta researchers to retrieve data in the commonly used formats of spreadsheets (Excel) and statistical software (SAS, S+). These software tools will be developed in collaboration with researchers at the LTER Network Office and in the LTER information management group.

Terabyte Scale Data Systems for Remotely Sensed Data - The increasingly obvious reality of working with remotely sensed data is that there are more data available and becoming available than we can make use of given our dependence on today's leading edge commercial technology. Attempts by Sevilleta researchers to work with digital aerial photography at over a terabyte per scene have added to this realization. And, the successful launch of the MODIS platform assures a steady stream of high-resolution, multi-spectral data that may hold the key to many landscape level questions on the Sevilleta. These data are only going to come bigger and faster. To wit**, we are entering into collaboration with David Bader, a researcher in UNM's widely acclaimed Electrical and Computer Engineering Department, to research**

the use of terabyte-scale data systems. Dr. Bader works with the UNM High Performance Computing Center and the San Diego Supercomputing Center on parallel algorithms and mass storage strategies for very large data systems. This collaboration will result in the development of new initiatives in this area.

A System of Sample Archiving - The long-term storage and management of physical samples is an issue that goes un-addressed in most ecological research projects. There are some classic examples like the soil archive at Roth Amsted, U.K. and some LTER examples like the hydrologic sample storage system in use at Hubbard Brook but there are no community standards to fall back on in this area. Sevilleta has water, soil, plant material, and animal tissue samples that must be managed for long-term reuse. The Museum of Southwestern Biology (MSB) currently manages Sevilleta animal tissue samples as vouchers (see below) but there are no systems in place for the management of other physical samples. **Sevilleta will research the use of physical sample archival storage and laboratory information management systems (LIMS) to either adopt or adapt a suitable system.** The results of this research will be made available to the LTER and broader ecological communities through the published literature and our web pages.

Improving the taxonomic registration and integrity of Sevilleta LTER Data -Studies of plant and animal species distributions and abundance's are essential to many of the Sevilleta long-term projects. Therefore, accurate species determinations are essential to the quality of the data generated from those research projects. Correct species identifications and validations can only be obtained by carefully assessing the qualifications of persons making species determinations in the field or lab, and by constructing and maintaining collections of voucher specimens that represent those species. We are convinced that the construction and maintenance of voucher specimen collections and corresponding databases is a crucial part of the Sevilleta information management and research program. **We will initiate a policy of taxonomic integrity of our biological data by including a taxonomic qualifications component to the evaluation process of any ongoing and new studies in Sevilleta III and by requiring research projects involving biological species to collect voucher specimens of the taxa they study, and to submit those specimens to the Sevilleta LTER voucher specimen collections.**

The Museum of Southwestern Biology (MSB provides ideal facilities and personnel to collaborate with the Sevilleta. We will formalize a long-standing relationship between the Sevilleta and the MSB, whereby MSB personnel will assist in evaluations of taxonomic integrity for LTER research projects, and the MSB and Sevilleta LTER will construct and share voucher specimen collections and databases. LTER personnel will collect voucher specimens. MSB and LTER personnel will work together to verify taxonomic identifications, and curate and database voucher specimens.

Improved Computing Infrastructure for Data Management - The Sevilleta took advantage of an NSF special supplement opportunity to upgrade network connections to the Sevilleta Research Field Station. The WAN equipment and connection between UNM and the field station is being upgraded to full T-1 speed (1.54 Mb/s) with a T-3 (45 Mb/s) capability that includes repositioning the termination point to the vBNS router. The LAN backbone and connections have been upgraded to 100 Mb/s with 384 Mb/s fiber between buildings.

VI. Outreach

Newspaper Articles/Television Broadcasts: The Sevilleta LTER Program has been featured on public television several times in the past year, and is participating in three productions for PBS/Educational TV. The three PBS productions deal with: 1) teaching the use of mathematics in solving problems using ecological experiments (the NSF-funded series, ``Math in the Middle of Nature"); 2) a program on biodiversity and the future of Man on the planet (another NSF-funded production, entitled ``Can We Survive?", and based on Sevilleta LTER data integrated with a National Academy of Sciences symposium on global biodiversity); and 3) a series produced by UNM and the New Mexico Museum of Natural History entitled, “Ecosystems of New Mexico” that was broadcast to public school science classes throughout the state. Numerous newspaper articles have quoted results produced by Sevilleta LTER researchers, including major stories in USA Today, U.S. News and World Report, The Scientist, Associated Press, and the local New Mexico papers (Albuquerque Journal, Albuquerque Tribune, the Socorro El Defensor-Chieftain, and the Farmington Sun-Times).

In 1998-99, the Sevilleta LTER was featured on the CBS, NBC, ABC, and CNN News in regard to possible Hantavirus problems associated with the 1998 El Niño. As a number of our predictions have come true, Sevilleta researchers Terry Yates and Robert Parmenter have been on national (CBS, ABC, NBC, CNN) and local news presentations discussing the relationships between climate, ecosystem productivity, animal populations and diseases. Parmenter also appeared on the CBS local news in June, 1998, explaining climate dynamics (droughts) and impacts on water availability and ecosystem responses in New Mexico based on the LTER studies. With respect to transferring LTER concepts and Sevilleta LTER results (as examples) in the international community, James Gosz has appeared on television broadcasts in a number of countries. This list includes Ireland, Spain, Taiwan (China-Taipai), Mongolia, Israel, Canada, Hungary and South Africa.

Public access to GPS CBS: Greg Shore (Sevilleta LTER GIS Specialist) designed and implemented a system for WWW and anonymous FTP public access to the Sevilleta LTER GPS Community Base Station (CBS) system. This provides C/A code and L1 phase code GPS base data access for all Internet-connected GPS users within a 300 km radius of the Sevilleta NWR.

UMEB/REU Program: The Undergraduate Mentorships in Environmental Biology (UMEB) Program (P.I. Robert Parmenter, plus many faculty mentors), a collaborative program with the Sevilleta LTER, finished its final year in spring 1999. In addition, in the summer of 1999, we started our renewed REU Site Program (P.I.’s Robert Parmenter and James Gosz) at the Sevilleta; the major emphasis of this program is to related biodiversity to ecosystem NPP in various ecosystem types across the Sevilleta NWR. The goals of these programs are to: 1) instruct undergraduates in the principles of scientific research; 2) expose the students to a wide variety of ecological research techniques and career opportunities; 3) facilitate individual student research projects, and 4) encourage students to continue their scientific education in upper-division courses and graduate school. The programs include: 1) orientation meetings and a seminar series devoted to the variety of scientific opportunities in ecological research at the Sevilleta; 2) faculty-student one-on-one instruction of hypothesis development and research protocols in ongoing Sevilleta LTER projects; 3) field and laboratory experiences in sampling and data collection; 4) implementation of individual student research projects, carried out under the guidance of student-selected faculty members; and 5) preparation and submission of project manuscripts to scientific journals. These activities integrate all theoretical and technical aspects of the LTER and promote a holistic approach to large-scale ecological studies. Information on the new REU Site Program can be found at http://sevilleta/research/outreach/reu/

Sevilleta Schoolyard LTER Activities: The Sevilleta's Schoolyard LTER Program is directed by Dr. Clifford S. Crawford, who has established our educational outreach program known locally as the “Bosque Ecosystem Monitoring Program” (BEMP). The major focus of this educational program is on the Rio Grande riparian cottonwood-forest (“bosque”) corridor through central New Mexico (including the Sevilleta National Wildlife Refuge). The Sevilleta LTER Program has conducted a number of research studies in the Rio Grande bosque at Sevilleta NWR and other local sites, and due to its popularity with, and importance to, New Mexican populations (particularly schoolteachers and K-12 students), we have chosen this particular ecosystem in which to develop the Schoolyard LTER. The BEMP has four main educational goals. These are to: 1) involve students and citizen volunteers of all ages in the coordinated monitoring of key processes and populations of the endangered Middle Rio Grande riparian forest ecosystem; 2) enable these participants to “learn by doing” about the natural history and ecology of the bosque near their communities; 3) use these students and volunteers to convey to their communities an appreciation of the scientific and social significance of long-term environmental research; and 4) give the students and informed citizens an opportunity to become involved in the management of a critical environmental resource.

The BEMP uses mainly secondary school teachers and their students to collect data relevant to the long-term management of bosque functioning. Data collection occurs synchronously and according to a predetermined schedule. Thus, a given set of variables is sampled on the same date at all four current BEMP sites. The sites are identical in layout and located between northern Albuquerque and the smaller city of Belen, NM, near the Sevilleta NWR. Site specific, abiotic data collected include soil and air temperature, precipitation and groundwater depth. Biotic data include litter production, plant diversity and indicator arthropod activity. Years of restoration related research on the bosque by UNM biologists have demonstrated the value of such data types and the relative ease of collecting them in the field.

Another goal is to finish the development of the databases and Internet homepage, so that the public (especially the teachers and students) can have easy access to the data sets as they develop. The BEMP data sets are currently being entered and archived on the Sevilleta LTER homepage, and should be completed during the proposed funding cycle (1999-2000). Homepage information on the Schoolyard LTER will include the Program Description (designed to recruit additional schools into the program), Goals and Hypotheses, Field Sampling Procedures, and the Data Sets: Weather, groundwater depths, vegetation composition, cottonwood tree demographic data, litterfall rates, and arthropod abundances. In addition, a major goal is to strengthen BEMP's community outreach and intersite communication. This will be accomplished through regular meetings, now underway, of staff and interns on the second and fourth Tuesdays of each month. The first meeting of the month is held at UNM and emphasizes intern reporting and intersite comparisons. The second monthly meeting is held at the Rio Grande Nature Center in Albuquerque and focuses on community outreach.