The Sevilleta LTER Program, managed by the Department of Biology, University of New Mexico, became part of NSF's LTER Program in 1988. At that time, the research theme of the Sevilleta LTER (SEV LTER) was about "Life on the Edge," or the impact of interannual climate drivers, particularly the El Niño Southern Oscillation, on biome transition zones in the southwestern US. Over time, the focus of our LTER research has expanded to embrace a new overarching goal:

to understand the causes of biotic transitions at multiple spatial and temporal scales, and the consequences of those transitions for ecosystem structure and function.

The Sevilleta LTER Project includes research on biotic transitions in grassland, shrubland, woodland and riparian ('bosque') forests. Each of these transitions is governed by changes in one or two key abiotic drivers, among them climate variability, fire, hydrologic variability and herbivores. Expanding the research to multiple types of transitions increases the generality of SEV LTER research as we tackle a series of parallel hypotheses being investigated within each transition zone, while also increasing the scope and relevance of our long-term research program to address state, regional and national issues.

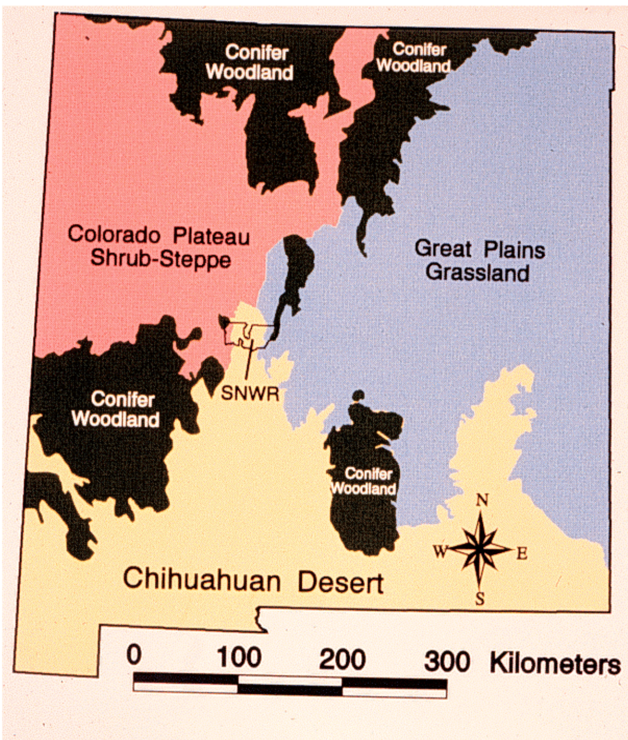


Figure 1. Location of the Sevilleta National Wildlife Refuge, central New Mexico, with respect to the major biomes of the region.

The Sevilleta LTER Project is located about 80 kilometers south of Albuquerque, New Mexico, in and around the Sevilleta National Wildlife Refuge (NWR). The Refuge, which is managed by the US Department of the Interior, Fish and Wildlife Service, and its surroundings, are positioned at the intersection of several major biotic zones: Chihuahuan Desert grassland and shrubland to the south, Great Plains grassland to the north, Piñon-Juniper woodland in the upper elevations of the neighboring mountains, Colorado Plateau shrub-steppe to the west, and riparian vegetation along the middle Rio Grande Valley (Figure 1). Because of the confluence of these major biotic zones, the Sevilleta NWR presents an ideal setting to investigate how climate variability and climate change act together to affect ecosystem dynamics at biotic transition zones. Moreover, the rapid growth and expansion of the City of Albuquerque and its suburbs to the north increasingly will have an impact on ecosystem processes at the Sevilleta, and these urban forces will interact with climatic variation to catalyze change in this aridland region.

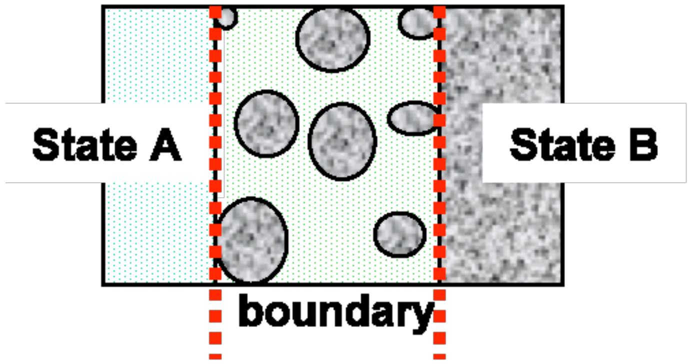


Figure 2. Conceptual model of biotic transitions at multiple spatial scales. A biotic transition consists of two states (A, B) with a boundary between them. The boundary consists of patches from both states that vary in size, type, spatial configuration, and degree of connectivity. The model is applicable across a range of spatial scales, such as individual plants where the boundary consists of root or leaf patches from each plant, assemblages of plants where the boundary consists of patches of individual plants of one species interacting with plants of a different species from an adjacent patch, associations or groups of plant assemblages where each assemblage dominated by one species is a patch, and the boundary consists of these interacting groups of plants, and landscapes consisting of a mosaic of boundaries and states at all smaller scales.

Key Biotic Transitions

Over the past two decades, one of the key organizing themes in ecology has been patch dynamics. Patch dynamics refers to a change in ecological properties within and among patches through time. A patch is a discrete, bounded area of any spatial scale that differs from its surroundings in its biotic and abiotic structure and composition. The historical emphasis on patch dynamics has led implicitly to the impression that patch change is driven by relatively consistent internal dynamical phenomena. Yet, in some systems, biotic transitions at patch boundaries may be the most dynamic aspects of patches, and processes occurring at boundaries may drive overall patch change. To address this variability and interaction, we developed a new conceptual framework for interactions at patch boundaries from which we derive testable hypotheses for studies of patch dynamics along biotic transitions, a term that we use to include boundaries at all scales (Peters et al. in revision, Figure 2). We are now using this framework to structure our LTER research along a dynamic grassland to shrubland transition zone at the Sevilleta.

Grassland and shrubland transitions. Grassland to shrubland transitions are occurring throughout the southwestern United States in response to a variety of biotic and abiotic drivers. At the SEV LTER, one of the major focuses of our research is the dynamic transition from blue grama (*Bouteloua gracilis*)-dominated grassland to Chihuahuan desert vegetation dominated by black grama (*B. eriopoda*) grassland and creosote (*Larrea tridentata*) shrubland on McKenzie Flats. Essentially, these three species form nearly monodominant patches that represent the end-member states of a complex array of patch types and animal species comprising this relatively abrupt transition zone.

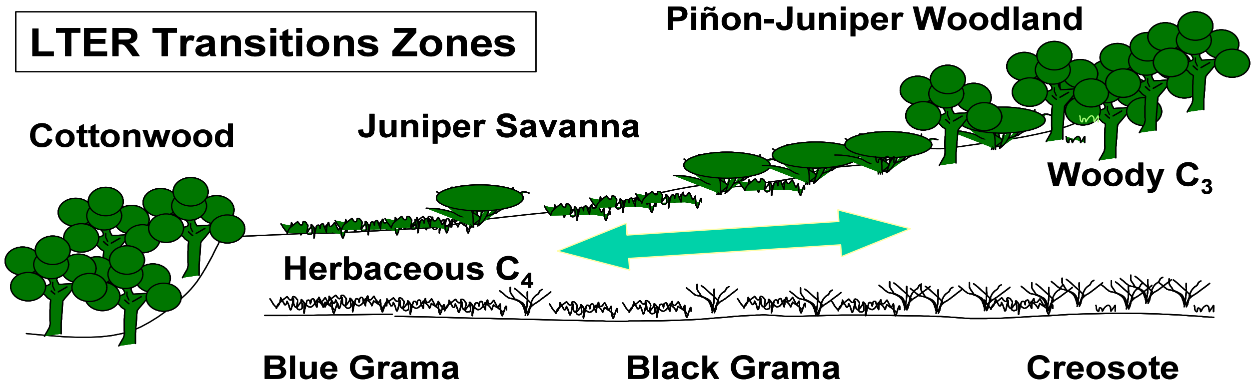


Figure 5. Schematic diagram of upland transitions at the Sevilleta National Wildlife Refuge.

Key drivers of dynamics in this transition zone are grazing, fire and soil water and nutrient availability. On-going experiments are addressing each of these processes (see findings). In addition to pervasive water deficits common in arid regions, the grassland to shrubland transition occurs on soils that are low in total, total nitrogen and nitrogen mineralization rates. Earlier hypotheses suggested that these depauperate soils were the product of historical overgrazing prior to the early 1970's. An alternative hypothesis is that surface soils are young and frequently reworked by wet and dry climatic cycles. Work by two graduate students, Lydia Zeglin (UNM Biology) and Debbie Bryans (UNM Earlth and Planetary Sciences) is addressing these hypotheses. Lydia is studying vegetation greenness and soil fertility in areas that are now grazed, areas that were fenced in 1993 and areas on the SEV that have not been grazed since 1973. Lydia has found that greenness is more a product of precipitation than grazing. However, she has observed that long-term ungrazed area on the on the Sevilleta do have greater soil organic carbon, total nitrogen and C:N ratios than grazed areas all of which supports the grazing hypothesis. Despite these changes in the absence of grazing, soil nutrient levels remain low compared to those found in other grasslands. Debbie Bryans, a soil scientist, is just beginning her detailed studies on soil structure and dynamics across the transition zone from grass to shrub dominance using a series of soil pits around the rainout shelters and in other parts of the transition zone.

Originally, we hypothesized that the dynamics of the grassland to shrubland transition were driven by climate dynamics associated with ENSO events. However, after three such events since the start of the LTER in 1989, there is little evidence that directional change is occurring across this biotic transition zone in response to El Niño or La Niña cycles (Li 2000, 2002). Another mechanism contributing to stasis along this transition zone is population declines in burrow-forming mammals, such as prairie dogs and kangaroo rats. The Dissertation work of Ana Davidson (UNM Biology) shows that disturbances by these animals greatly enhance diversity of plants, total small mammals species richness, birds, ground dwelling arthropods, and herps. Also, these disturbances affect the local distribution and abundance of soil resources (Ayrabe and Kieft 2000). Kangaroo rat mounds are common on the Sevilleta, but prairie dogs are rare. In response to the recent LTER Site Visit, we are planning to incorporate more studies on the impacts of fossorial mammals on Sevilleta grasslands.

Piñon-Juniper woodland transitions. The savanna to woodland transition occurs along an elevation gradient on the north end of the Los Pinos Mountains. This transition zone was part of the original Sevilleta LTER program in 1989, but activities there were reduced over time. This transition begins with savanna characterized by scattered individuals of *Juniperus monosperma* and a dense understory of perennial grasses (primarily *Sporobolis* spp.) to woodland of *J. monosperma* and *Pinus edulis* with a sparse herbaceous understory. In the piñon-juniper woodland, total soil nitrogen and carbon are comparable to levels in other sites across North America, but like in the grassland on McKenzie Flats, nitrogen mineralization rates in PJ soils are extremely low (Zak et al. 1994).

Originally, we hypothesized that the elevational boundary between savanna and woodland was a function of occasional periods of extreme drought. Evidence supporting this hypothesis can be found in the dead juniper carcasses located at the foothills of the Los Pinos Mountains on the east side of the Sevilleta NWR. It is now believed that these long, severe droughts are the product of the PDO, which is hypothesized to have a return interval of 52±11 years (Milne et al, 2003). Currently, the southwestern US is experiencing a severe and prolonged drought, which has many of the characteristics of that experienced in the early 1950's, and a massive die-off of pines and juniper is occurring throughout the region. Bark beetles and fungal pathogens help to increase tree mortality as individuals are weakened by drought. Circumstantial evidence from fertilization experiments at the Sevilleta suggests that piñon mortality rates may be higher in areas of greater resource abundance, thus we hypothesize that mortality of patches of pines may be exacerbated by regional patterns of drought coupled with gradients in atmospheric nitrogen deposition. Overall, this is a significant regional transition that may be part of a long-term cycle from woodland to grassland and back as climate fluctuates on decadal time scales.

To address this question, we have continued to monitor mortality rates in the piñon-juniper woodland, monitored seed and cone production on a set of permanently marked individuals to piñon pine, juniper and oak, and continue to measure root turnover in fertilized and unfertilized plots in the piñon-juniper woodland. Also, we resumed measurements of aboveground net primary production in the herbaceous layer of these forests, and we are in the process of installing tree diameter bands on about 100 individuals to measure rates and changes in tree growth over time.

Riparian zone transitions along the Middle Rio Grande Basin. The Rio Grande, which bisects the State of New Mexico, contains the second largest drainage basin in the southwestern US. Within New Mexico, >60% of the state's population lives along the river and that population is rapidly growing. The Rio Grande provides a considerable amount of surface water for agricultural and other uses and demands on that water are increasing at unprecedented rates. Ecologically, a dramatic biotic transition within the riparian zone ('bosque') is occurring in the Rio Grande Basin as the native forest of cottonwoods is rapidly being replaced by two widely dispersed non-native species, Russian olive and salt cedar. This transition is creating significant ecological challenges related to state and regional water management and policy (Dahm et al. 2002). Although the original Sevilleta LTER research program did not extend into the Middle Rio Grande riparian zone, we feel that doing so now represents a key opportunity to regionalize the Sevilleta LTER and to address important ecological and management issues in the State of New Mexico. In this case, the middle Rio Grande Basin extends from Otowi Bridge near Santa Fe south through Albuquerque and the Sevilleta to

Elephant Butte Reservoir about 150 kilometers south of Albuquerque. Climatically, this region varies from the south where moisture deficits are more severe to the north where there is an increasing period of greater summertime water availability.

Historically, changes in these riparian ecosystems were driven by flood frequency and intensity. Now that the river is highly regulated, floods are rare, the hydrologic regime has been drastically altered, and human-caused fires are common. Since 1990, over 50% of the bosque in the Middle Rio Grande basin has burned. We hypothesize that these changes in disturbance regime will enhance rate of replacement of native species, increase evapotranspiration, and reduce nitrogen retention in the riparian zone.

A fire occurred in mid April 2003 in the bosque just off the Sevilleta in a stand that has been monitored since 1999 as part of a restoration project in the middle Rio Grande. Vegetation is being re-surveyed and soil parameters measured to determine the impact of this fire on forest regeneration. Although some of the cottonwoods were sprouting after the fire, it appears that salt cedar is increasing rapidly at the expense of cottonwood in this stand.

FINDINGS

We have organized our research efforts around three interrelated system components: abiotic drivers, ecosystem processes and biotic responses and feedbacks. In our case, the main abiotic drivers are (1) seasonal, annual and decadal variations in climate, (2) geomorphology, soil texture and depth, and surface hydrology, and (3) season and periodicity of fire. These abiotic drivers affect biogeochemical cycles, particularly nitrogen, phosphorus and carbon, as well as water storage, use and losses. Biotic responses to the coupling of these abiotic drivers and ecosystem processes include patterns and controls on net primary production, and the distribution, abundance, diversity and dynamics of plant and animal populations and communities. Although there is considerable research linking primary production and plant community structure (Waide et al. 1999, Mittelbach et al. 2001), one of the core activities of the Sevilleta LTER has been investigations of fluxes in NPP and their impact on the distribution and abundance of consumers, particularly small mammal populations (Ernst et al. 2001, Friggens 2003). This has direct relevance to human health issues in response to the regional prevalence and potential outbreaks of vector-borne diseases, such as Hanta and Plague (Yates et al 2003).

KEY ABIOTIC DRIVERS: CLIMATE AND WATER

A pervasive limiting resource in these aridland ecosystems is water. In central New Mexico, precipitation inputs vary seasonally, annually and on decadal time scales. In the southwestern US, the amount and timing of seasonal and annual precipitation are influenced by two major climate cycles, the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). ENSO

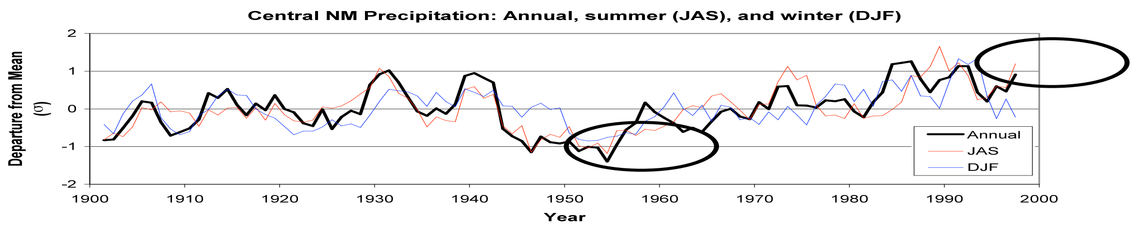
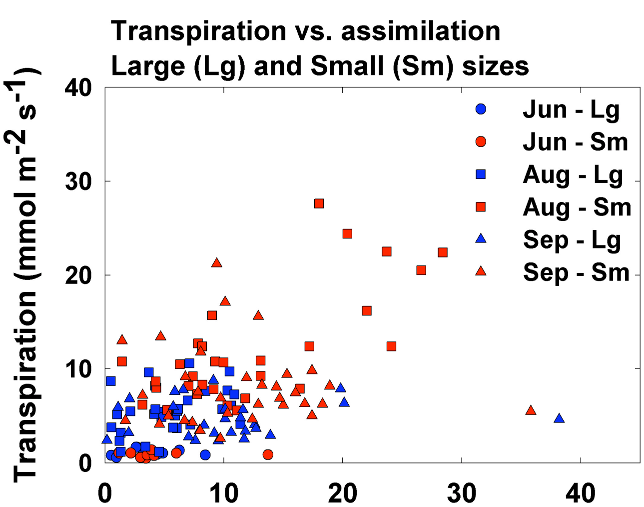


Figure 2. Precipitation patterns for central New Mexico from 1900-1999. Note the regional drought during the 1950's was characterized by low precipitation in both summer and winter seasons.

regulates variability in winter precipitation with high precipitation occurring during El Niño periods, and low precipitation during La Niña periods. ENSO events typically occur every 3-4 years and usually last only through one winter season. More recently it has been suggested that a longer-term climatic event, the Pacific Decadal Oscillation, may have profound effects on regional climate in the southwestern United States (Gutzler et al. 2002). The PDO, which oscillates on approximately 50-year cycles, modulates ENSO events and it may be the cause of periodic, extended, severe droughts in the region (Milne et al. 2003, Fig, 2).

To experimentally investigate the effects of drought on ecosystem processes in these aridland ecosystems, we have nearly completed installation of a series of rainout shelters in grass-, transition and shrub-dominated areas. Rainout shelters were established with funds from SAHRA, an NSF-funded Science and Technology Center at the University of Arizona and SEV LTER. In 2002-2003 growing seasons Pockman and Small (in prep) analyzed the effects of a pulse precipitation event in the transition zone rainout shelters on



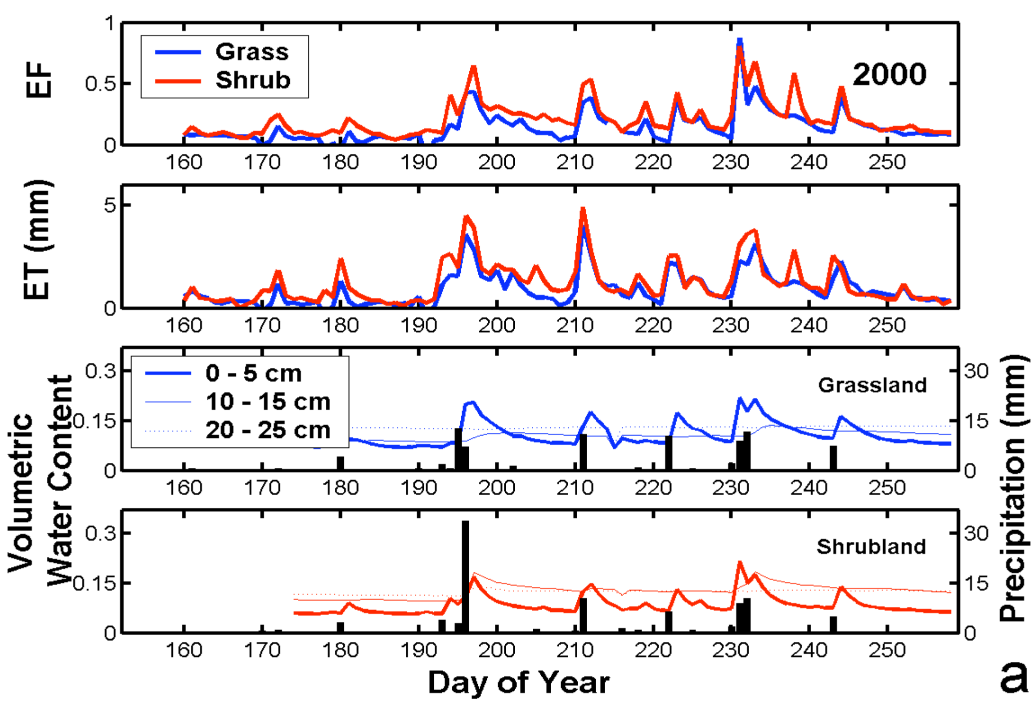
Fgure 1: Growth and water use responses to Summer Monsoon 2002. Small plants were growing faster and using water less conservatively than large plants during the monsoon season of 2002 and Spring 2003, but not during the dry seasons of 2002 and 2003. Though the two sizes did not differ significantly in predawn or midday water potential, in a two-way ANOVA with date and canopy volume as predictors, small plants had significantly higher rates of AM transpiration conductance and photosynthesis, and conductance at midday (a = 0.5). These differences were largest during the summer monsoon of 2002. Small plants responded more to monsoonal moisture than large plants, but their responses to low soil water potentials were very similar to that of large plants.

soil moisture flux and plant responses. These shelters also serve as focal sites for research by Sevilleta graduate students Shirley Kurc (Univ Colorado) and Juliana Medeiros (UNM). Juliana tested two hypotheses on small and large plants in a population of *Larrea tridentata* located

at the Sevilleta LTER in central New Mexico: (1) do small plants grow faster and use water less conservatively than large, and (2) are there differences in the hydraulic constraints on small and large plants. Shoot growth, gas exchange and plant and soil water potentials were measured in the field every six weeks to determine growth rates, water status and water use from April 2002 – August 2003. Measurements of leaf specific conductance determined the ability of the xylem to supply water to the leaves. A model was used to determined the hydraulic constraints on each size based on xylem vulnerability curves and soil texture analysis, which were used to determine the hydraulic properties of the plant xylem and soil. Excavation findings were used to estimate (A_R:A_L) for the model.

Shirley Kurc is conducting her dissertation research on ecosystem level fluxes of water, energy, and carbon cycling in semiarid grassland and shrubland at the Sevilleta. She has collected and analyzed water, energy, and carbon data from two Bowen ratio stations and from two eddy covariance stations (1 of each within grassland and shrubland) which also include soil moisture measurements at several depths. Her research in the summer of 2003 focused on partitioning ET into transpiration and evaporation at the grassland and shrubland in an effort to understand the different controls on ET at these sites. Measurements of evaporation and transpiration were made 3 times a day for a minimum of four days following rainfall input. Evaporation was measured using micro-lysimeters and soil chambers. Transpiration was measured

Figure X. Daily time series of evaporative fraction (midday), ET (daily total), volumetric water content (0-5 cm, 10-15 cm, and 20-25 cm), and precipitation (bars) for summer 2000. Grass is represented by a blue line and shrub by red line. Grassland (blue) and shrubland (red) plots are separate for water content and precipitation.



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using leaf gas exchange and whole plant chambers. Midday plant water potential was also measured daily. Data collected this summer are currently being analyzed.

Ecosystem processes: Biogeochemistry and Decomposition

A Major focus of our research in 2003 centered around a planned 6000 ha fire on McKenzie Flats, in part of our intensive study area. The fire occurred from 19-22 June 2003. As noted above, nitrogen pools are very low in these desert grasslands. We hypothesized that fire would increase potential N_{min} rates and increase plant available nitrogen in response to the summer monsoons. To test this hypothesis, soil cores were collected immediately after the fire from burned and unburned areas in fertilized (10gN per m^2) and control treatments on McKenzie Flats. These soils are now being incubated to determine potential N mineralization rates. Soil bridges were installed and measured to determine soil erosion rates following burning. In addition, ion exchange resin bags were buried in burned and unburned areas at the south end of McKenzie Flats. Resin bags were collected at the end of the summer monsoon season and are being analyzed for plant available NO_3, NH_4, and PO_4. Results from these measurements are still being analyzed.

Nitrogen availability is also a function of moisture inputs, plant uptake rates, and time intervals between rainfall events. Soil N availability following drought intervals was determined with long-term Nmin data from the SEV plus new data collected at a grassland area north of Albuquerque. There is a positive association between length of time between precipitation events and N_{min} indicating that nitrogen accumulates during drought intervals (White et al. submitted). Thus the production response to precipitation following drought is not only a function of precipitation, but time since the last rainfall event. This leads to the hypothesis that production responses to equal sized precipitation events may vary depending on the time intervals between events.

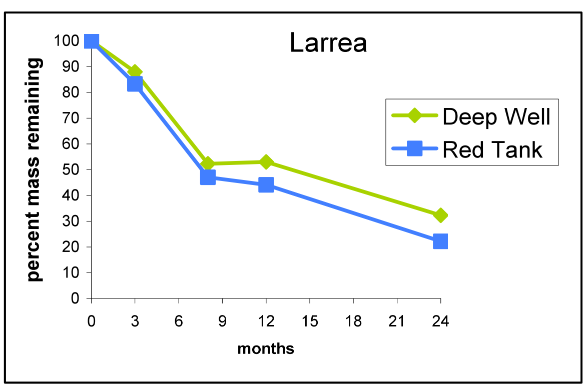


Figure 1. Deep Well and Red Tank are very similar with respect to average annual precipitation and temperature, but Deep Well is dominated by black grama and blue grama , while Red Tank is dominated by juniper and creosote. Differences in the microbial community between sites may result in more rapid decomposition for creosote at Red Tank.

The decade-long Sevilleta Long-Term Plant Litter Decomposition Project (1990-1999) was designed to investigate site, species, litter quality, and climate influences on decomposition. Litter from *Bouteloua eriopoda* (black grama), *Bouteloua gracilis* (blue grama), *Oryzopsis hymenoides* (ricegrass), *Juniperus monosperma* (juniper), and *Larrea tridentata* (creosote) was used in this study. Analyses were done with data from Deep Well, Cerro Montosa, Red Tank, and Rio Salado.

Climate and litter quality variables were largely unrelated to decomposition. Mean percent litter mass remaining after one year was rarely correlated with total annual precipitation, number of rainfall events per year greater than 6 mm, initial litter C:N, initial litter N:P, or average annual temperature for any species at any site. Possible examples of biotic control are illustrated in the two figures below.

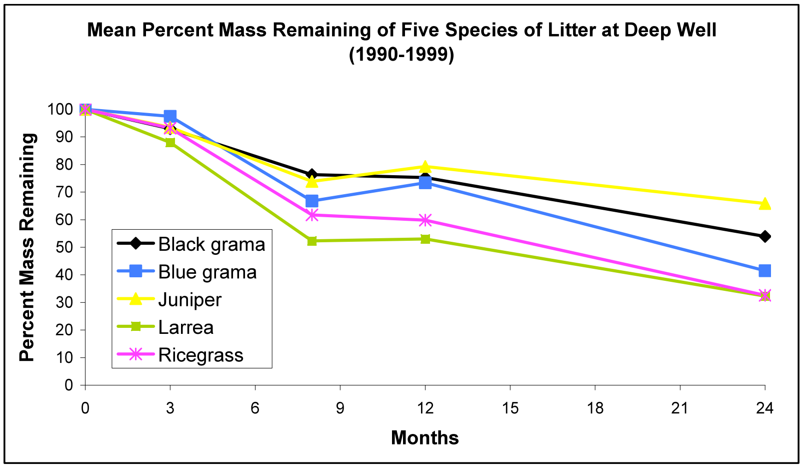
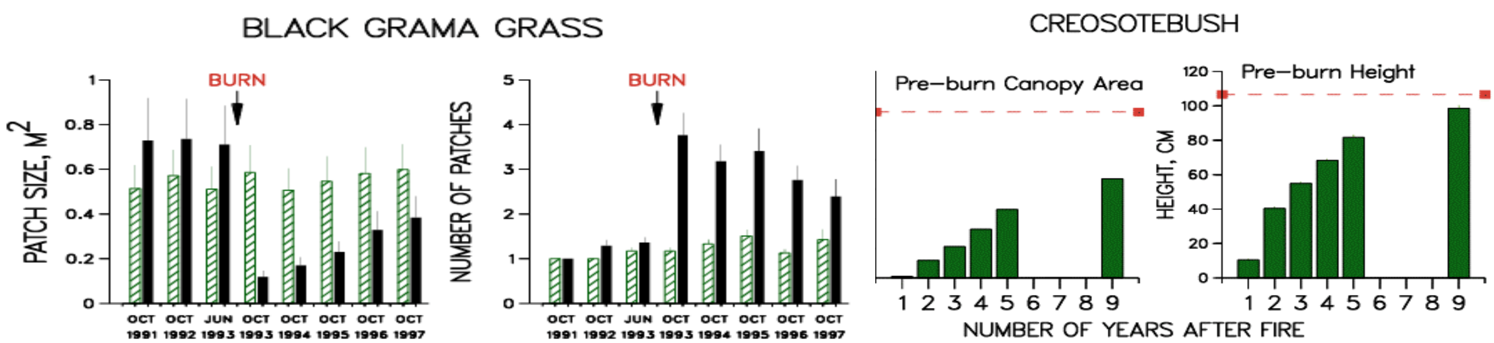


Figure 2. Creosote decomposed more rapidly than the other species at all sites. Average initial C:N of creosote litter was 21, while initial C:N of juniper, ricegrass, blue grama and black grama ranged from 65-75.

BIOTIC RESPONSES: PRODUCERS AND CONSUMERS

One of the key questions in arid systems is whether or not black grama (*Bouteloua eriopoda*) can recover from summer fire. Long-term vegetation studies following a wildfire in 1995 suggest that it does recover but more slowly than its main competitive, blue grama (*B. gracilis*). Follow-up studies are now underway following the 2003 management burn where we established monitoring plots prior to the burn (Figure X).

Figure X. Response of black and blue grama and creosotebush to a summer fire.



OTHER ACCOMPLISHMENTS AND FUTURE GOALS

One of the challenges for any LTER site is to seek a balance between understanding the details of a particular research site and addressing a suite of broadly based questions derived from ecological theory. We believe that research at the Sevilleta LTER site has led to a number of significant accomplishments of broad scientific significance and of relevance for the growth and maturation of the SEV LTER Program. Here we highlight several of those accomplishments and then describe our objectives for the next phase of research and development of the program..

Long-term research at the Sevilleta has documented the considerable resilience of these nutrient-poor, aridland ecosystems to disturbances, such as fire and grazing (e.g., Gosz and Gosz 1996, Ryerson and Parmenter 2001, Peters 2002a,b). The region has a long history of grazing, and in some cases, this has led to significant ecosystem degradation. In addition, the site has experienced several lightening-caused fires over the past 10 years. In both cases, there is clear evidence that species composition, soil resources, and standing crop biomass have returned to predisturbance conditions relatively rapidly (Munson et al., in prep). This resilience is somewhat surprising given the extreme environmental constraints that govern biotic processes in this region.

When the Sevilleta began, many thought that biotic transitions in the Southwest would be strongly driven by interannual variation in climate, particularly in response to ENSO events. However, long-term research at the Sevilleta demonstrates that this original ENSO hypothesis is not correct. Not only are these ecosystems resilient over time, but they also appear to be relatively stable across large spatial scales. There is little evidence of large-scale biotic transition being driven by ENSO events (Li 2000, 2002).

Detailed mechanistic studies coupled with long-term data led us to conceptualize a broadly applicable general model of biotic transitions that links patch and edge dynamics (Peters et al., submitted). Traditionally, patch dynamics and boundary dynamics have been treated as somewhat independent phenomena. But, in many cases, the dynamics of a patch are explicitly a function of the dynamics of the patch boundary. As landscapes worldwide continue to be modified by human activities, boundaries will be an increasingly important feature of landscapes. Our patch dynamics-boundary dynamics model can provide a framework for understanding the causes and consequences of landscape change in other ecosystems.

Through a suite of observational and manipulative experiments, we have gained knowledge that is specific to the Sevilleta study area concerning end-member interactions and dynamics in each of our study systems (e.g., Gosz and Gosz 1996, Peters 2002, Bhark and Small 2003). By end-member interactions we mean detailed understanding of pattern and process in core areas dominated by blue grama, black grama, creosote bush, riparian forests, and piñon-juniper woodland. Through this knowledge, we will now begin to expand our efforts into more complex mixtures of species to more fully understand the dynamics of biotic transitions in space and time.

One of the advantages of LTER is the opportunity to establish long-term experimental manipulations that provide the foundation for integrated studies of ecological systems. To that end, we have garnered external funding to initiate a long-term, integrated rainfall manipulation experiment. Rainfall manipulation shelters are being used to modify ambient climatic variables to allow us to more fully understand the role of water inputs and fluxes in these arid land ecosystems, as well as how well these ecosystems recover from extended drought.

LTER programs generate a considerable amount of complex data, and information management is one of the key goals of the LTER Network as a whole. The Sevilleta LTER has implemented an information management system fully in compliance with LTER Network goals and objectives. The information manager interacts with researchers from project inception to conclusion to ensure that well-documented, high quality data are archived and made publicly accessible within two years after the project ends. Research at the Sevilleta is supported by a UNIX server offering file, web, and email services as well as software including SAS, ArcInfo and ERDAS Imagine. Synthethic research and educational activities by the broader community of ecological scientists is fostered by Sevilleta contributions to network-level databases such as ClimDB, translation of Sevilleta metadata into EML (the LTER network metadata standard), and participation in research projects such as SEEK, the Scientific Environment for Ecological Knowledge.

Finally, the Sevilleta LTER is proud of its educationally ambitious and scientifically rigorous Schoolyard LTER Program. This program, the Bosque Ecosystem Monitoring Program (BEMP), meets national and state educational standards for science education, involves over hundreds of school kids each year, connects K-12 students and teachers with UNM undergraduate interns and faculty, provides a source of curriculum activities for school teachers, and produces scientifically rigorous long-term data on the riparian ecosystems of the middle Rio Grande Basin. Currently, BEMP includes 14 school systems throughout the Middle Rio Grande Basin, including two Indian Pueblo schools, a variety of schools in the City of Albuquerque, plus rural school systems as far south as the Sevilleta.

Over the past year, the Sevilleta LTER Program has changed dramatically in response to unfavorable proposal reviews and the last site visit. In direct response to these criticisms, the program has (1) acquired new leadership, (2) broadened the overarching conceptual framework, (3) recruited new investigators especially from within UNM, (4) regionalized the research program, and (5) created new opportunities to enhance graduate and undergraduate participation. With these changes, we feel confident that the SEV LTER can and will remain a strong and viable member of the LTER Network well into the future.