Contributions

Contributions within Discipline:

The Sevilleta LTER has contributed to several important questions within the discipline. In particular, we have shown that aridland vegetation is resilient to haevy grazing by cattle. Results from our long-term studies show that many of the grasslands on the Sevilleta are once again dominated by long-lived perennial C4 grasses and native forbs. We are now experimentally determining the resilience of these systems to climate extremes including chronic drought and multiple wet years. Finally, we have shown for the first time that shrub encroachment leads to a decline in plant species richness and decreased temporal stability of subordinate species.

We are involved in a multisite analysis of the ecosystem impacts of shrub encroachment and its impacts on aboveground NPP and plant community structure. Unlike previously reported results, shrub encroachment has minimal effects on NPP in aridland ecosystems, but evidence shows greater net carbon storage with shrub encroachment. Thus, desertification may increase carbon storage in aridlands.

Detailed analyses of soil moisture fluxes show the ability of these systems to respond to precipitation pulses, and that these responses differ somewhat in grassland and shrubland primarily as a function of differences in total vegetation cover, but not in water use, per se. Our new monsoon rainfall manipulation experiment will directly test hypotheses about rainfall pulse events. In that context we have revised the aridlands pulse reserve model and developed a 'fungal loop' model for aridland ecosystem processes in which fungi, rather than bacteria, are the key drivers of C and N dynamics.

Our new long-term rainfall manipulation experiment in the Pinon-Juniper woodlands at the Sevilleta is designed to determined the mechanisms by which chronic severe drought interactions with tree ecophysiology, bark beetles and fungal diseases to explain regional scale tree mortality and rapid large-scale ecosystem change.

Our continuing efforts to restore Gunnison's Prairie dog colonies on the Sevilleta is providing a unique research opportunity to determine the keystone role of this species in aridland ecosystems.

Sevilleta personnel continue to play a role nationally in the development and implimentation of EML, and in training information managers nationally and internationally on modern methods and goals of information management.

Contributions to Other Disciplines:

We continue to maintain our strong linkages between ecological research at the SEV and geoscience research, especially geomorphology and soils, hydrology and climatology. The Sevilleta serves as a site for the development of models to better predict the North American Monsoon and for scaling up evapotranspiration losses regionally. Current work reflects a collaboration between soil scientists and hydrologists on soil CO2 fluxes and how this affects soil development and nutrient transfers in aridlands.

Our various long-term global change experiments focuse on how climate change and atmospheric deposition will affect population, communinity and ecosystems processes in a variety of habitats characteristic of this aridland region.

Because of our extensive wireless cloud the east side of the Sevilleta and beyond, Sevilleta scientists continue to play a leadership role in the development and use of wireless technology for environmental research in both monitoring and experimental contexts.

Contributions to Human Resource Development:

See attached activities file. Also, the Sevilleta Schoolyard LTER program, BEMP (Bosque Environmental Monitoring Program), connects K-12 kids to ecosystem monitoring and research through field and classroom activities all up and down the Middle Rio Grande. These activities were greatly assisted by Education Enhancement funds received in 2005 and 2006, and a boost in the LTER core funding for BEMP.

This is the third year of our GK12 program where 10 UNM Graduate Fellows from the Departments of Biology and Earth and Planetary Sciences assist middle school teachers with science content and inquiry based activities at schools in Socorro, Belen and Laguna Pueblo, NM. The Fellows also work with after-school programs and the development and planning of multi-day field trips with the students, teachers and parents.

The Sevilleta also serves as a testbed for the development and implimentation of wireless sensor networks and sensor technology. These projects are scalable, and can be translated to other ecosystems. The SEV provides a technological challenge to the engineers and computer scientists who are developing this technology because of its abundant sunlight and high temperatures. We continue to work in collaboration with scientists at Los Alamos National Labs and with faculty members in the UNM Mathematics Department to develop on-the-fly visualization and data analysis protocols in two of our signature global change experiments.

We have installed a wireless backbone on the Sevilleta which can serve as a prototype for wireless systems at other relatively remote LTER sites.

We continue to involve undergraduate students in all phases of our project through hiring of summer interns and through our newly established Sevilleta LTER REU program. In 2008, we hosted 10 REU students, 9 of which came from colleges and universities outside of New Mexico.

In 2007, PI Collins served as a mentor for Jarrod Blue one of the ESA SEEDS Research Fellowship awardees. Jarrod is now a graduate student at the University of Tennessee and he plans to return to work with BEMP staff in the summer of 2009 to work up some of the long-term arthropod data from riparian areas along the Middle Rio Grande.

Contributions to Resources for Research and Education:

See attached activities file. Also, BEMP continues to provide science experiences for hundreds of school kids living along the Middle Rio Grande. Our GK12 program continues to serve as a bridge between the Sevilleta LTER and Sevilleta graduate students with the Sevilleta National Wildlife Refuge, and the middle school science classes in Socorro, Belen and Laguna Pueblo.

Our prairie dog restoration project is helping to establish viable populations within the Sevilleta National Wildlife Refuge of this potentially threatened species.

Contributions Beyond Science and Engineering:

Our research provides key information and understanding about aridland ecosystems that is used by the Fish and Wildlife Service in making management decisions. For example, in cooperation with staff at the Sevilleta National Wildlife Refuge, we began a long-term experiment to determine the impacts of seasonal management burns on plant community structure, soil nutrient fluxes and NPP. Fire is a key management tool at the SNWR and this research will inform managers about the seasonal impacts of fire on management goals. We hope that over time, this project will also include fire frequency treatments.

Work by Sevilleta scientists on ecosystem processes and restoration in the bosque is contributing directly to the development of a state water plan, and water management through ecological restoration. Plans for extensive restoration continue in 2007 and Sevilleta scientists are actively involved in planning, designing and monitoring these riparian restoration efforts.

Our prairie dog restoration project is a highly visible conservation effort to create viable populations of this threatened species within the Sevilleta. This is a cooperative activity between the SEV LTER, the US Fish and Wildlife Service, and scores of volunteers.

In addition, with EPSCoR funding and pending proposals we hope to determine the role of high elevation pinon-juniper and juniper savanna ecosystems in ground water recharge, a crucial issue in the arid southwestern US. Pervasive regional drought has caused large scale die-offs in these ecosystems which will have a significant impact on fire frequency and wildlife populations, among other things.

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Any Web/Internet Site

Any Product

Activities

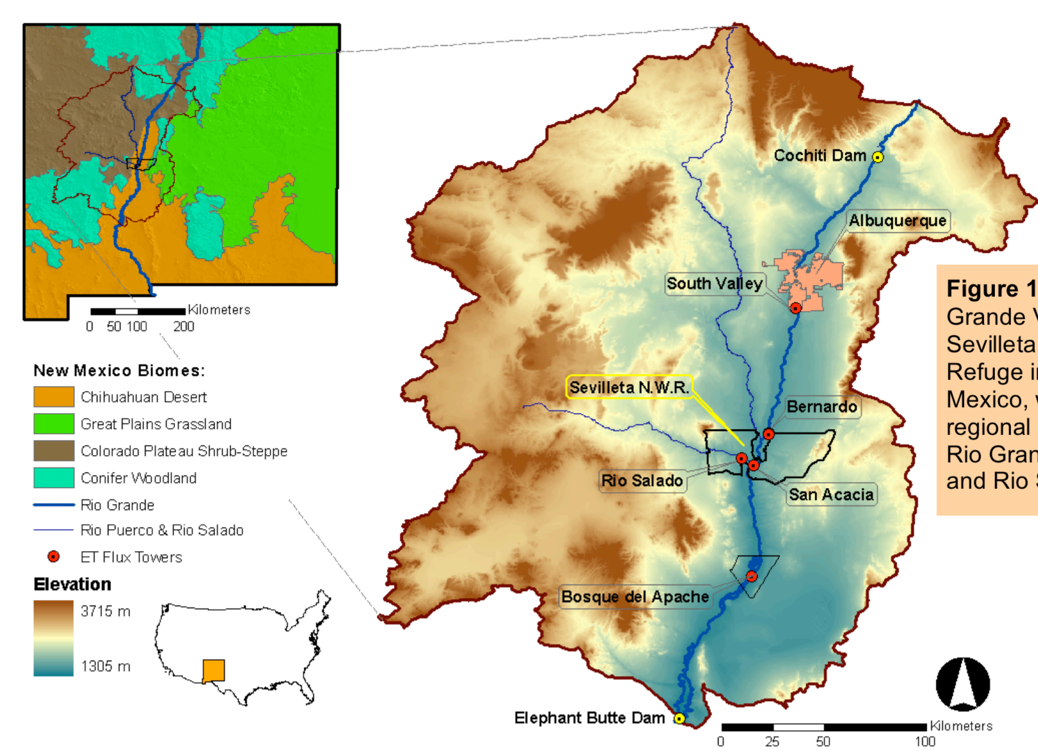


Figure 1. The Middle Rio Grande Valley and Sevilleta National Wildlife Refuge in central New Mexico, with respect to regional biomes and the Rio Grande, Rio Puerco and Rio Salado.

The Sevilleta LTER Program addresses ecological concepts and theory through a comprehensive and interdisciplinary research program in desert grassland, shrubland, forest and riparian habitats in central New Mexico. Our focal sites are the 100,000-ha Sevilleta National Wildlife Refuge (SNWR) located about 80 kilometers south of Albuquerque (managed by the US Department of the Interior, Fish and Wildlife Service) and the Middle Rio Grande (MRG) bosque between Cochiti Dam and Elephant Butte Reservoir (Fig 1). Since its inception in 1988, the Sevilleta LTER program has conducted research at multiple ecological levels and a variety of spatial and temporal scales. Our studies are linked by an overarching theme that considers **how abiotic drivers and constraints affect dynamics and stability in aridland populations, communities and ecosystems.**

The Sevilleta LTER Program is a long-term, comprehensive, integrated, interdisciplinary research program addressing key hypotheses on pattern and process in aridland ecosystems. Our LTER research in central New Mexico is concentrated on studies in desert grassland and shrubland communities and piñon-juniper and riparian (‘bosque’) woodlands emphasizing transitions in space and time. Each landscape component is governed by key abiotic and biotic drivers, especially climate variability, fire, hydrologic variability, nutrient dynamics, and herbivory. The rates and intensities of these drivers are changing over time. Given the emerging research interest in ecohydrology of aridlands, our focus on the effects of biotic and abiotic drivers on spatial and temporal dynamics of these aridland ecosystems allows us to conduct long-term research that addresses important basic ecological questions and yet has significant relevance to state, regional, national, and international priorities.

The Sevilleta LTER site 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

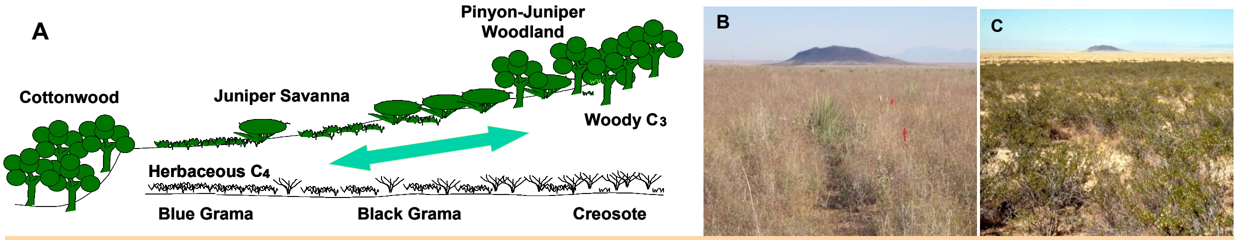


Figure 2. A) Schematic diagram of upland transitions at the Sevilleta National Wildlife Refuge. B) Black and blue grama grassland at Deep Well. C) Creosote dominates 4 km south.

the north and east, piñon-juniper woodland at upper elevations in the mountains, Colorado Plateau shrub-steppe to the north and west, and riparian vegetation along the middle Rio Grande Valley (Figs 1 and 2). Because of the confluence of these major biotic zones, the SNWR and the Middle Rio Grande Basin present an ideal setting to investigate how environmental change and climate variability interact to affect ecosystem dynamics at the boundaries of major biomes in southwestern North America. Moreover, the rapid growth and southern expansion of the City of Albuquerque and its suburbs increasingly will have an impact on ecosystem processes throughout the Middle Rio Grande Basin, including the SNWR, and these urban forces will interact with climatic variation to catalyze change in this aridland region.

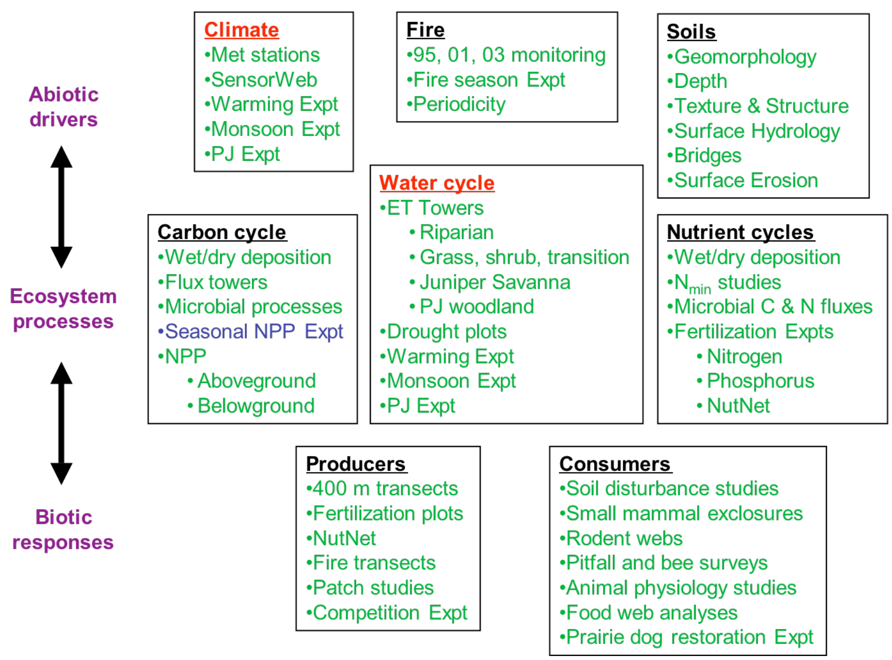


Figure 3. **Current** (GREEN) and **Planned** (BLUE) activities of the Sevilleta LTER Program, with a major focus on climate and water cycle interactions

This is the second annual report from our fourth funding cycle. LTER IV (2006-2012) builds on our prior research on patch and boundary dynamics by placing a greater emphasis on interactions among key processes and drivers of change in aridland ecosystems, in particular nitrogen (N) availability and climate dynamics. This new emphasis greatly expands the spatial and temporal scales and conceptual bases of our LTER program. Our new organizing framework is designed to integrate the components of our research program and allow us to test important hypotheses of general ecological interest.

More specifically, Sevilleta research is designed to understand the individual and interactive effects of three key system components: abiotic pulses and constraints, ecosystem processes, and biotic responses and feedbacks (Fig 3). The main abiotic *pulses* and *constraints* are (1) seasonal, annual, and decadal variations in climate, (2) geomorphology, soil texture, structure and depth, and surface and riparian hydrology, and (3) season, periodicity, and intensity of fire. These abiotic factors affect *dynamics* of biogeochemical pools and cycles; water input, storage, use and loss; and patterns and controls on primary production. Biotic responses to the coupling of these abiotic factors and ecosystem processes include *dynamics* and *stability* in the distribution, abundance, and diversity of plant and animal populations and communities. Given the fundamental relationship between primary production and community structure in ecological communities, one of our core LTER activities is to link climate dynamics, disturbances, and soil structure with soil nutrient and water fluxes to better understand seasonal and annual variability in NPP and how that variability ultimately affects the dynamics, distribution and abundance of key aridland producers and consumers.

Figure 4. Photo of irrigation event in the piñon-juniper rainfall manipulation experiment in the Los Piños Mountains at the Sevilleta LTER.

To accomplish these goals, the Sevilleta LTER program is organized into five overlapping thematic areas with designated group leaders: Climate and Abiotic Drivers (Cliff Dahm), Water Fluxes (Will Pockman), Soils and Biogeochemistry (Bob Sinsabaugh), Producer Dynamics (Esteban Muldavin), and Consumer Dynamics (Blair Wolf). These thematic areas are not mutually exclusive, but they serve as an effective mechanism to organize and synthesize our research. New and continuing research includes a variety of activities in each sub-area (Fig 3).

In 2007-2008 we continued all but one long-term data collection efforts described in our renewal proposal (LTER IV) and in the 2006-2007 annual report. These activities include (1) our multiple factor global change experiment that manipulates nighttime temperature, N-deposition, and winter rainfall frequency, (2) a summer monsoon rainfall manipulation experiment, (3) our rainfall manipulation experiment in piñon-juniper woodlands (Fig 4), (4) continued efforts at restoring Gunnison's prairie dog colonies on the Sevilleta, (5) use of stable isotopes to understand food web dynamics, and (6) monitoring of CO2 and H2O fluxes in riparian, grassland and shrubland, and installation of additional CO_2-ET flux towers in piñon-juniper woodland and juniper savanna. Another tower will be erected in the grass-shrub ecotone this fall to measure CO_2, H_2O and energy balance in this transitional ecosystem, as part of a new NSF-funded collaborative project with researchers at the University of Virginia (Paolo D'Odorico, Jose

Fuentes, Stephan DeWekker). We discontinued the cattle grazing study because the formerly grazed property has been sold for development. Also in 2007-2008, a number of Sevilleta LTER graduate students and REU students have conducted important short-term measurements and experiments on climate, biogeochemistry and soils, water and nutrient cycling, producer, and consumer communities. Highlights of results from a subset of these activities are provided in "Findings."

Riparian ET and water fluxes
The riparian corridor of the Rio Grande on and near the Sevilleta LTER has been the focus of long-term ecohydrological and bio-meteorological studies. An eddy covariance flux tower was installed in the spring preceding the 1999 growing season and has been operating since. This tower was initially installed to measure evapotranspiration and energy fluxes. Supporting activities have included vegetation surveys, plant water relations measurements and studies, groundwater dynamics and chemistry, scaling and classification using remote sensing, remote data collection using telemetry, and characterization of the surface layer for water, energy, and carbon dioxide fluxes.

Producer dynamics in response to disturbances
We continue to examine the effects of small, patchy disturbances on vegetation dynamics across grassland-shrubland ecotones. Five sites have been monitored since 1995 and the sixth was added in 1998. At each site, five 3 m x 4m plots were established by removing all plants of the dominant vegetation. An additional 5 control plots with no removals serve as controls at each site. We also added a series of 5 plots with total removals at each site in 2003. Sites are dominated by either blue grama, black grama, blue and black grama, creosotebush, or black grama and creosotebush. We monitor vegetation cover by species annually on each plot. Long-term monitoring is needed to determine the species that will dominate following the loss of the current dominant.

Simulation modeling
In collaboration with the JRN LTER, we continue to modify the ECOTONE simulation model by incorporating the horizontal and vertical distribution of water, nutrients, and soil particles by wind and water across a range of spatial scales, from plants to patches and landscape units. We are working with Greg Okin at UCLA to link ECOTONE with his model of wind redistribution of soil particles to incorporate effects of dynamic vegetation on wind erosion-deposition dynamics. We recently started working with Enrique Vivoni of NM Tech to link ECOTONE with his hydrologic models. In addition, we have an ARS postdoc at the JRN who is working with SEV Senior Scientist Deb Peters and Ed Fredrickson to develop an animal model to link with ECOTONE as part of our overall ENSEMBLE modeling effort.

Thermal biology and activity of desert box turtles (Ian Murray, Blair Wolf and Emily Stinson (REU))

At this point, 33 unique desert box turtles have been captured and measured on the Sevilleta. Data collected from these animals includes growth ring keratin samples, blood, morpho-metrics, and various environmental data. Twenty-three of these animals were animals not previously marked, while the remainder were animals marked in past years, some as long ago as the 1980s

(Germano pers. comm.). In addition, the inclusion of 6 juvenile and hatchling box turtles, size classes rarely seen, will provide a more complete picture of the ecology of this animal on the Sevilleta.

REU student **Emily Stinson** worked with SEV Graduate Student Ian Murray to sample box turtles in 2008 at times of high turtle activity. She developed a project using Thermochron iButtons (miniature temperature dataloggers) to study desert box turtle thermal ecology. By attaching the iButtons to the carapaces of the animals, and pre-programming them to record at 15 minute intervals, we can determine when the animals are emerging from their burrows, how long they are active, and when they re-enter shelter. Compared with iButtons at stratified heights in the environment, one can actually come up with a fairly solid time budget for these animals. We have 20 turtles equipped with dataloggers, and have recaptured and downloaded temperature data from 5 of these animals to date. We continue to search for turtles on the Sevilleta, and hope to recapture additional animals before activity ceases for the year. Emily is pursuing this topic as her senior thesis at Hamilton College.

Data will be processed and analyzed during fall and winter 2008-2009. A small strip of keratin has been collected from many of the captured turtles. This strip holds a sequence of every growth ring an animal has produced over its life, similar to a tree ring chronology. Together with blood plasma and red blood cell samples, we can model the nutritional ecology of these turtles, via stable isotope analyses, over the course of their lives. We will combine available climate data with growth ring measurements and iButton temperature profiles, to paint a robust and revealing picture of the ecology of an otherwise obscure inhabitant of the Sevilleta, the desert box turtle.

The utilization of pulsed resources by a grasshopper community as quantified from breath $\delta^{13}C$ using tunable diode laser absorption spectroscopy (Sophia Engel, Blair Wolf and Ashley Melendez (REU))

Isotopic breath analysis can be used to determine the diet recently consumed by animals. We measured the $\delta^{13}C$ of expired "breath" CO_2 of a grasshopper community from the Sevilleta LTER using tunable diode laser absorption spectroscopy. This approach allows the quantification of the utilization of specific plant functional groups, as defined by photosynthetic pathway (C_3 or C_4), by grasshoppers and to determine its variation over the course of a season. Measurements of breath $\delta^{13}C$ show that resource use by the grasshopper community and its temporal variability is diverse.

Publications and grants.

In 2008, Sevilleta LTER scientists have published 32 papers thus far with 11 more currently in press and several more manuscripts are currently in review. One of these publications describes our pulse-dynamics model for aridland ecosystems (Fig. 5) that we use as one of the integrating themes for our LTER research (Collins et al. 2008). Also, in 2008 Sevilleta LTER scientists received funding from NSF and DoE. One of the NSF awards is the collaborative project with UVa scientists, **"Collaborative research: Do vegetation-microclimate feedbacks promote shrub encroachment in the Southwestern United States?"** UNM PI's are Marcy Litvak, Will Pockman and Scott Collins. The proposed research will develop field and modeling activities to investigate and quantify the feedbacks between encroachment by a native C_3 shrub, *Larrea tridentata,* into native C_4 grassland, and the consequent changes in surface energy balance in a northern Chiuhuahuan desert ecosystem. To this end, the project will (1) test the hypothesis that *Larrea* encroachment leads to decreases in surface albedo and increases in thermal energy storage in soils with the overall net effect of increasing nighttime air temperatures capable of favoring the establishment and viable growth conditions for *Larrea* plants; and (2) assess whether and where this vegetation-microclimate feedback can induce conditions of ecological bistability in the dynamics of aridland ecosystems thereby limiting their resilience. The second award was to support an REU Sites Program at the Sevilleta LTER. The PI's are Scott Collins

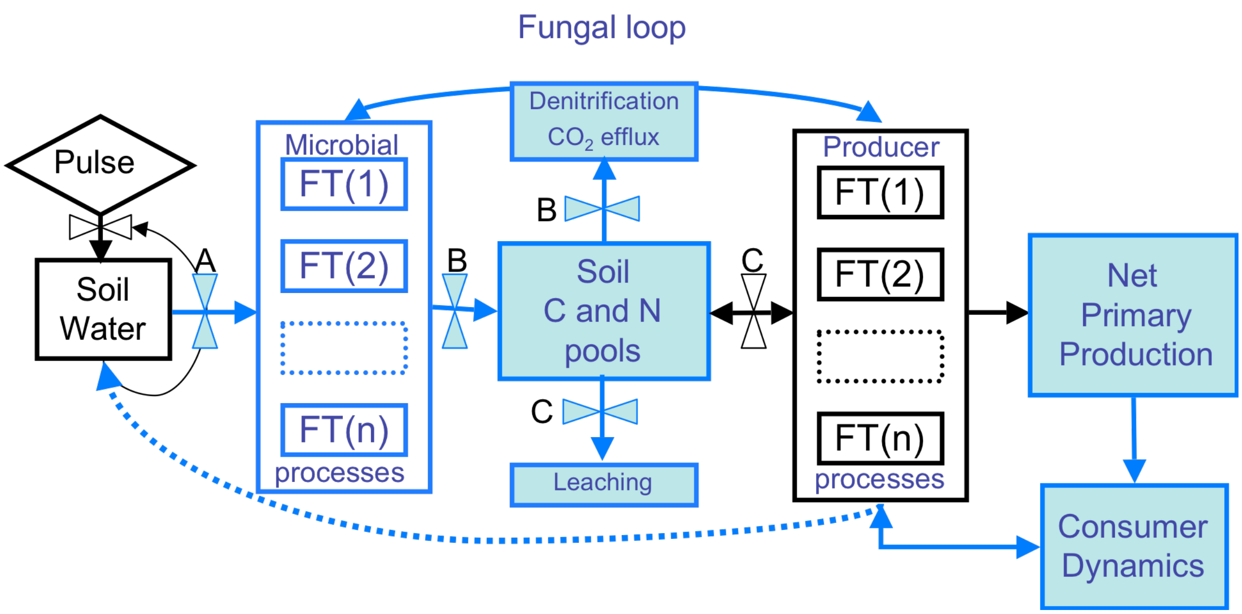


Figure 5. The threshold-delay nutrient dynamics (TDND) model for aridland ecosystems (modified from Ogle and Reynolds 2004 and Reynolds et al. 2004). The TDND model includes key features of aridland ecosystems, including the role of pulse precipitation events, antecedent soil moisture, time lags and plant functional types. New additions (in blue) to the model include C and N dynamics, the key role of microbial functional types in the C and N cycles, and potential feedbacks by consumers. FT=functional type.

and Les McFadden (Dept Earth and Planetary Sciences, UNM). In addition, we successfully competed for DoE NICCR funding to support the on-going work in our three main grassland-shrubland global change experiments. The objective of this research entitled, **"Ecosystem consequences of precipitation variability and extremes in semiarid grassland and shrubland,"** is to understand changes in ecosystem structure and function of semiarid grassland and shrubland caused by a) extended periods of severe drought or above-normal precipitation and b) precipitation variability. These forcings alter the pulses of soil moisture that drive biotic activity, such as primary productivity, community composition and ecosystem function. Using existing infrastructure, this work assesses the long-term consequences of disparate precipitation forcings. The PI's on this award are Will Pockman, Scott Collins, and Eric Small (Univ Colorado). Additional Sevilleta-related proposals are currently pending with DoE and NSF.

In addition, to research activities, important and exciting developments continue to occur at the Sevilleta Field Research Station. Phase I of the Sevilleta Education and Research Facility

(SERF) was completed in 2007 (Fig 6) and Phase II is nearly complete. Visiting scientists from Southern Illinois University and several REU students used lab space in the new SERF facility this summer. Phase II includes space for offices, a professional kitchen, dining area, a classroom/lecture room, and a computer training facility.

Figure 6. The Sevilleta Education and Research Facility (SERF).

Information management. Managing streaming sensor data at the Sevilleta LTER is a challenge because of the volume of data and because automated mechanisms are needed to do quality control. In Fall 2007, as a first step toward improving data quality, Sevilleta began to generate visualizations of the data to help researchers detect malfunctioning instruments. A student programmer was hired to create scripts that would produce daily, weekly, and monthly plots of the temperature and moisture data from the Sevilleta's Warming and Monsoon experiments. It was soon clear that the ten-year-old Sevilleta Sun E450 server could not handle the processing of the scripts without shutting down essential network services. This graphing project has been placed on hold. Meanwhile, out-of-range values are being flagged as the sensor data are ingested into the Sevilleta MySQL database.

With money from the 2008 Sevilleta supplement, two new Sun Fire X4140 servers have been purchased. When the servers are in place, we expect to see significant performance improvements in the Sevilleta database, web site, and email systems.

Sevilleta continues its quest for a solution that will facilitate the conversion of legacy metadata and new metadata into EML. Inigo San Gil of LNO continues to work on a program that will convert a structured text file of metadata in to level 5 EML. The program is believed to be close to completion. To hopefully improve the ease of metadata entry for Sevilleta personnel, a new data entry interface was designed in MS Access and implemented by a student programmer who was hired for 2.5 months during Summer 2008. The new interface has the added benefit of capturing metadata in a SQL Server database housed at LNO.

Education, Outreach, Cross-site and Network Level Activities.
The SEV LTER continues its activity involvement in education and outreach through BEMP (our Schoolyard LTER), the SNWR, E-MRGE (our GK-12 program), a newly funded REU Sites program, ESA SEEDS, and our everyday classroom teaching activities. SEV scientists are also active in numerous cross-site and synthesis projects, and provide service to the LTER Network.

Schoolyard LTER. The SEV schoolyard LTER/Bosque Ecosystem Monitoring Program (BEMP) is dedicated to science, education, and stewardship, bringing together each year over 2,000 K-12 students, their teachers, and UNM researchers to monitor and understand the Rio Grande and its riverside "bosque" forest (Fig 7). BEMP is coordinated by Drs. Cliff Crawford (Professor Emeritus, UNM Biology) and Kim Eichhorst (BEMP Science Education and Information Specialist), and Jen Schuetz, Program Administrator. Currently, BEMP organizes field and classroom activities at a variety of sites along the Middle Rio Grande in collaboration with more than 20 school systems, including the Albuquerque Public Schools, local private schools, one home school, several rural schools and two Pueblo schools. Each month, students use 22 research sites spanning 250 km of the Rio Grande to gather key indicators of structural and functional change within this complex ecosystem. These data are published in reports and used by local, state, tribal, and federal governmental agencies. Most BEMP students are from traditionally underrepresented groups in environmental education including large numbers of

Figure 7. BEMP students checking a rain gauge (left) and measuring water table depth in the Rio Grande Bosque.

Hispanics and Native Americans. BEMP sponsors an upper level undergraduate/graduate biology class at UNM in which students from the sciences, education, communication, and other departments learn about the bosque ecosystem while serving as interns within the program. The interns act as liaisons between researchers and K-12 students, take on quality control duties, assist in field data collection, lab analyses, and are mentors to the K-12 students. BEMP activities meet national and state education standards for K-12 science, math, social studies, and also include lessons in art and language, as well.

Through a variety of funding sources, including core NSF LTER support, BEMP staff coordinate field activities and design in-class exercises and materials, including a lending library of lesson plans and activity kits that BEMP interns and teachers can readily use with K-12 students. In addition, a professional educator works with BEMP staff to develop and present classroom activities in the context of ongoing bosque science. All activities are translated into Spanish and placed on the BEMP website (http://www.bosqueschool.org/BEMP/bemp.htm) as both a service to existing BEMP classrooms and as a recruitment and expansion tool. This year, because we received an REU Sites award we were able to direct additional LTER Supplement funds ($36K rather than $24K) to BEMP.

Undergraduate education. UNM is a certified Hispanic serving institution, and the Department of Biology has over 1200 undergraduate majors of which 48% are Caucasian, 33% Hispanic, 10% Native American, 7% Asian and 2% Black. Thus, through our day-to-day activities UNM faculty regularly work with, encourage, mentor, and train a large number of minority students. In that regard, we serve the broader goal of recruiting minority students into ecological research.

Figure 8. Left: Summer institute middle school students setting up pitfall traps with Sevilleta LTER Graduate Student and GK12 Fellow Andrew Edelman. Right: Summer institute middle school students noosing lizards at the Sevilleta with LTER Graduate student and GK12 Fellow Robin Warne.

In 1996, ESA established SEEDS (Strategies for Ecology Education, Development and Sustainability) to diversify and advance the profession of ecology. A key goal is to stimulate and nurture the interest of underrepresented students in ecological research. In 2005, UNM Biology established a local SEEDS Chapter (Collins is faculty rep). In Septermber 2008 the Sevilleta LTER hosted a research visit and career forum for the SEEDS chapters at NAU and UTEP. In addition, the Sevilleta LTER has offered to host the next national SEEDS Leadership conference.

K-12 Outreach. In 2006 we started E-MRGE, our GK-12 program in Ecohydrogeology in the Middle Rio Grande Environment (PI Collins, Co-PI Laura Crossey (Dept. Earth and Planetary Sciences)). E-MRGE Fellows work in partnership with middle school teachers in three rural New Mexico communities (Belen, Socorro and Laguna Pueblo) and the SNWR outreach program. Fellows and teachers develop activities to learn about long-term research and then develop related inquiry-based projects that provide hands-on science experiences for middle school students. These active learning projects are designed to meet New Mexico science standards. Several of our GK12 Fellows are also conducting part or all of their dissertation research at the Sevilleta.

In July of 2008 12 middle school students from our three GK12 schools attended a week-long summer internship at the Sevilleta National Wildlife Refuge organized by Sevilleta LTER graduate student and GK12 Fellow Juliana Medeiros (Figs. 8 and 9). Participants included 5

Figure 9. Left: Summer institute middle school students setting up mammal trips at the Sevilleta LTER site under the direction of GK12 Fellow Jason Thomas. Right: Summer institute middle school students learning about volcanic geology from GK12 Fellow Mel Strong.

other GK12 Fellows and one middle school teacher from Socorro, NM, the incomparable Theresa Apodaca. Students participated in data collection and instruction in Botanical Illustration, Sedimentary geology, Orienteering and topographic maps, Bird netting, Lizard capture, Arthropod pitfall traps, Small mammal trapping, Plant identification and Sevilleta plant communities, and Volcanic geology. The middle school students also had dinner with and interacted with our summer REU students. The program was a great success based on feedback from the students:

"This camp will influence the rest of my life because I will remember how fun it is to hike, catch rodents and do astronomy." Jessica Ridley, Belen MS

"I now have a better respect for the scientist and nature itself." Lucy Schulz, Belen MS

"I've always enjoyed science and learning but this program made my interest grow. Seeing how scientists work has made me want to become one. " Rebecca Salinas, Socorro MS

"The experiments we did here have helped me learn what, how and why scientists do what they do. A scientist does not have an easy life, they have a hard one. Long hours of research, few nights of sleep and temperatures are not easy but this is what a scientist goes through. I have had an awesome experience and will miss this place terribly. I wish we had another week here." Bryn Botko, Socorro MS

"I hope to later become a scientist and do research on the Sevilleta." Sam Boykin, Socorro MS

REU Program. Our formal REU Sites program began in 2008. There were ten REU students in residence at the Sevilleta Field Research Station (Fig 10). Students live at the Sevilleta during the summer and interact frequently with their mentors. This program includes a weekly journal club, a seminar series, a course in scientific ethics, and informal events to foster interactions among the various researchers and staff working at the SNWR. Our program is coordinated by Jennifer Johnson, one of the SEV LTER Research Scientists. This year students came to the Sevilleta

Figure 10. Left: 2008 Group Shot of Sevilleta interns, REUs, graduate students, researchers, and Sevilleta LTER and Fish and Wildlife Staff pose for a group shot during the annual West Mesa Tour on RUE orientation day. Center: REU Ashley Schaffer collect samples from pitfall traps. Right: REU Molly Ladd programming a data logger at the pinon - juniper research site, to capture sap flow measurements in tree roots.

from the University of Colorado, University of Mary Washington, University of Wisconsin Eau Claire, UTEP, Hamilton College, Bates College, Middlebury College, University of New Mexico, Ursinus College and New Rochelle College.

Network-level interactions. At the Network level and beyond, SEV LTER scientists continue to be involved in a variety of cross-site and international projects. IM Kristin Vanderbilt serves on NISAC and is also the chair of the ILTER Information Management Committee. In April 2008 she organized a workshop of thirteen ILTER metadata specialists who gathered at Lake Taihu Field Station in China to strategize about creating an ILTER Network information management system. The ILTER Coordinating Committee has since endorsed the recommendations from this workshop to 1) adopt EML as the ILTER metadata standard in order to generate a common ILTER metadata catalog, and 2) to engage with the international community in the standardization of ontologies and thus be in step with other organizations when tools for semantically annotating data become available. In addition, IM Vanderbilt frequently lectures in national and international training sessions organized by the LTER Network Office (LNO). PI Collins represents the SEV on the LTER SC. Finally, SEV researchers are involved in synthesis efforts such as ecoTrends, PDTNet (Suding et al. 2005, Pennings et al. 2005, Clark et al. 2007, Collins et al. 2008b) and other cross site projects on compensatory dynamics (Houlahan et al. 2007), shrub encroachment (Knapp et al. 2008), and the international Nutrient Network (NutNet) to name a few.

In collaboration with B. Bestelmeyer (JRN), we continue to sample vegetation responses in plots set up in 2000 to study the role of small animals on grass recruitment across a climatic gradient that includes three sites in the Chihuahuan desert. The sites range from the Sevilleta in central

New Mexico to the Jornada Basin and Range LTER in southern New Mexico to Big Bend National Park in southwestern Texas. Three locations were selected at each site, consisting of an ecotone between black grama grassland and an alternative dominant species, either creosotebush (SEV), honey mesquite (JRN) or chino grama (Big Bend). Cages were installed in 2001, and response variables have been measured annually during peak plant growth. We are monitoring black grama basal diameters and assessing plant growth and colonization of all species within each plot. We also monitor small mammal abundance along these ecotones using mark and recapture trapping procedures.

Sevilleta scientists were co-authors on four of six articles in the Frontiers in Ecology and the Environment special issue in continental-scale research led by Deb Peters, SEV senior scientist and JOR LTER PI.

Sevilleta LTER continues to participate in the National Phenology Network. In addition to these activities, the Sevilleta LTER is part of a five site social sciences funding collaboration (JOR, CAP, SGS, KNZ and SEV), "**Socio-ecological gradients and land use fragmentation: a cross-site comparative analysis.**" The objective of this cross-site collaboration is to answer the following research question: *Is the degree of land fragmentation a function of magnitude and/or rate of change of water availability, population growth, and urbanization?* At each site we will investigate the role of these drivers, in addition to other proximate drivers, in the process of land fragmentation.

In an effort to promote cross-site research and communication, the Sevilleta LTER hosted a regional annual symposium with scientists from JOR, CAP, SGS, NWT and KNZ presenting synthesis talks and poster presentations along with breakout groups to coordinate existing and potentially new cross-site research activities. At this cross-site workshop we agreed to hold a multi-site workshop once every three years. Thus, on a three year cycle these sites would hold, one site-based meeting, one regional meeting and then attend the LTER All Scientists meeting.

Sevilleta LTER scientists were involved in the establishment of a Southwestern Chapter of the Ecological Society of America. This Chapter was initiated to allow us to coordinate research efforts regionally. The request and justification for the chapter were drafted by Deb Peters (JOR), and the letter was signed by people from the SEV (Collins, Parmenter), JRN (Sala, Havstad, Herrick, Bestelmeyer), Konza (Knapp), and CAP (Briggs).

Together these activities illustrate how the SEV LTER and its scientists are committed to the goals of the LTER Network, as well as education, outreach and training at K-12, undergraduate, graduate, postgraduate, and informal levels.

Findings

As noted above, our research program is based on the concept of pulse dynamics in which pulses of rainfall, primarily at the event scale, stimulate biological processes from microbial metabolism through plant production and consumer population dynamics. The main components of our research are climate drivers, water in the environment, biogeochemistry and soils, producer dynamics, and consumer dynamics. Below we present highlights of some of the key results from our research in 2007-2008.

Climate variability (Doug Moore, Scott Collins)

General circulation models predict that our climate will continue to become more variable and a recent publication by Diffenbaugh et al. (2008 J Geophys Res) suggested

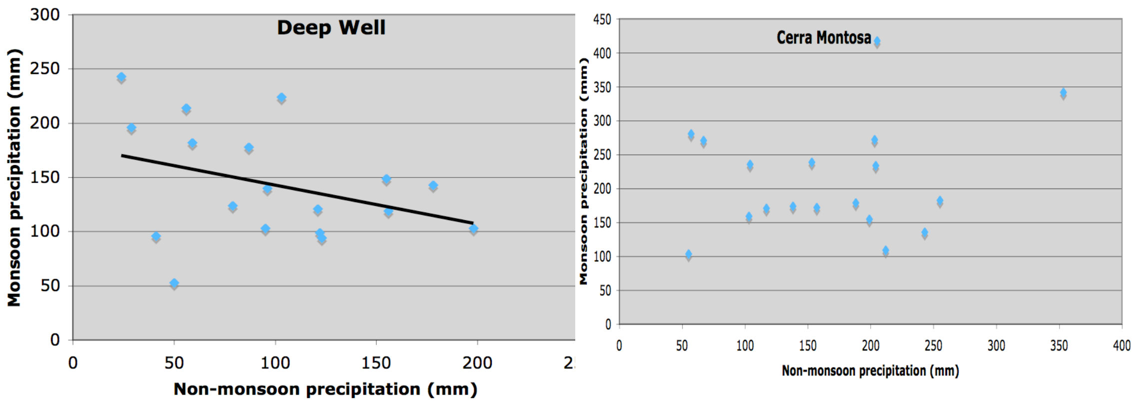


Figure 1. Annual precipitation during the summer monsoon season (July through September) versus non-monsoon precipitation in *Bouteloua*-dominated grassland at Deep Well (Left) and pinon-juniper woodland in the Los Pinos Mountains at the Sevilleta LTER site.

that within the lower 48 states ecosystems in the southwestern US would be most responsive to increases in climatic variability. Precipitation is already highly variable in desert environments, yet it is unknown how greater climate variability will affect aridland ecosystems. Here, we show the relationship between non-monsoon (October-May) and monsoon (June-September) precipitation at two sites at the Sevilleta (Fig 1). Deep Well is a *Bouteloua*-dominated grassland located on McKenzie Flats whereas Cerra Montosa is a high elevation piñon-juniper woodland on the north end of the Los Pinos Mountains. As expected, precipitation is higher in the woodland compared to the grassland. Another key difference is the negative relationship between winter and summer precipitation in the grassland, which does not occur in the woodland. In effect, intra-annual precipitation variability has thus far been biased by few years with low precipitation in both winter and summer, and no years with high winter plus high summer precipitation. These patterns may govern differential system responses to interannual variability across ecosystems at the Sevilleta and serve as a background for all of our current long-term rainfall manipulation experiments.

Evapotranspiration, water table fluctuations and riparian ecosystem dynamics (Cliff Dahm, James R. Cleverly, Kristin Vanderbilt, James R. Thibault)(Fig 2)

Figure 2. Aerial view of the South Valley of Albuquerque ET measurement site looking south down the Rio Grande. The tower is located in the wider portion of the bosque in the foreground. The bridge in the background is the Interstate 25 Bridge over the Rio Grande near Isleta. This photo was taken in the early summer of 2000 before the June 2006 fire.

Water table depths have ranged from nearly 4 m below ground during a severe drought in 2003 to flood stage during high river flows, in particular spring runoff in 2005. Within each site, total growing season ET declines with deeper water tables, with strong correlations at BDAS and LARO (Fig 3). Among sites, however, water table depth is not

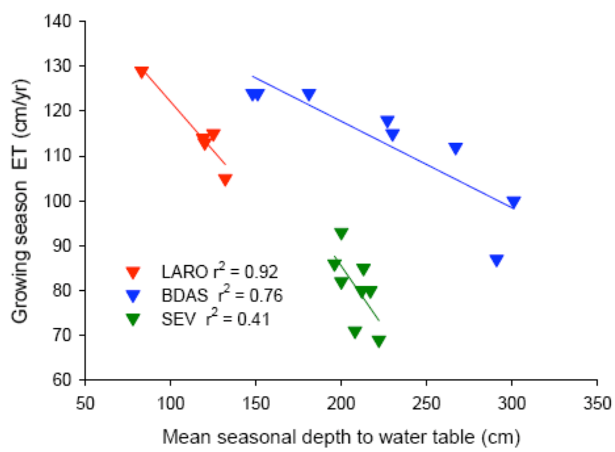


Figure 3. Left: collecting water samples. Above: Mean seasonal water table depth vs. ET, 2000 through 2007 growing seasons at Bosque del Apache (BDAS) and Sevilleta (SEV) National Wildlife Refuges, and 2003 through 2007 growing seasons at La Joya State Game Refuge (LARO).

a good indicator of ET, which is similar at the shallowest (LARO, 1.2 m) and deepest (BDAS, 2.3 m) sites, while the lowest ET rates are found at the intermediate depth site (SEV, 2.1 m). The two sites with stronger correlations between water table depth and ET, BDAS and LARO, have much more dynamic hydrographs. At these sites, water table depths fluctuate throughout the growing season by an average of 2.3 m and 1.5 m, respectively, while the mean range at SEV is 0.6 m. Ratios of range in depth to mean depth are > 1 at BDAS and LARO, but only 0.3 at SEV. Daily water table levels fluctuate at BDAS and LARO an average 6.3 cm and 4.1 cm, respectively, and 1.7 cm at

SEV. In these riparian areas characterized by near surface ground water, it appears that variability in water table depth, which exposes a greater extent of vadose zone throughout the growing season, may play a more important role than depth itself on transpiration rates by phreatophytes.

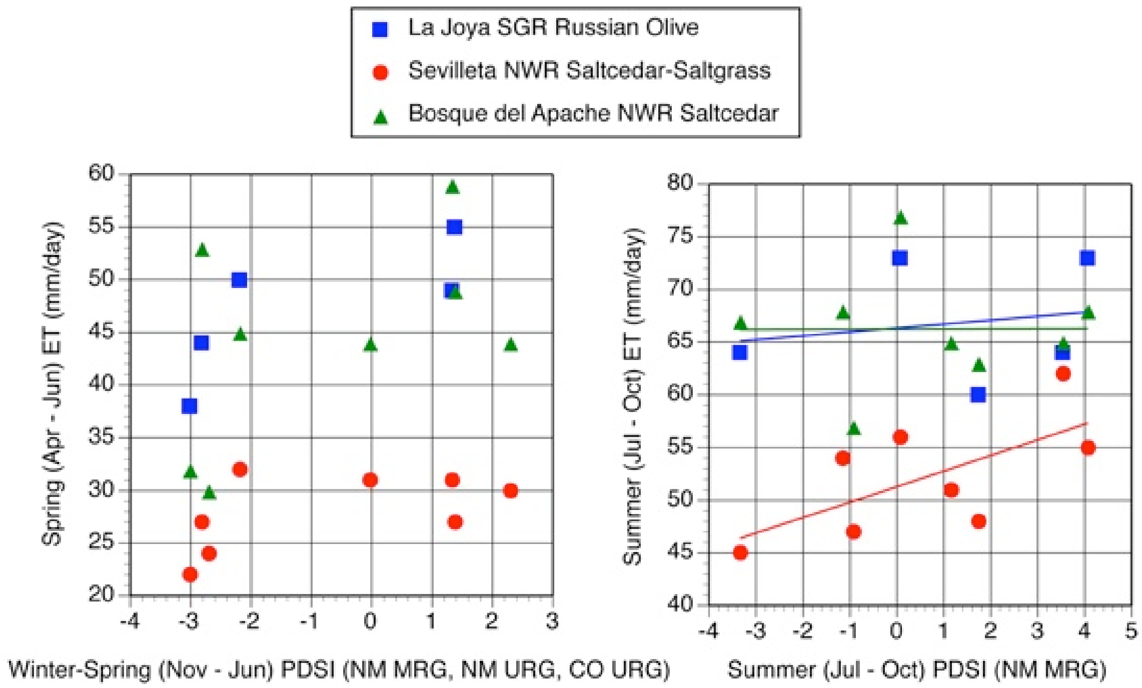


Figure 4. Spring and summer ET in Russian Olive, Saltcedar-saltgrass and Saltcedar ecosystems along the middle Rio Grande bosque

The vegetation along the Middle Rio Grande is phreatophytic, relying not upon local precipitation for a water source, but upon groundwater originating as higher-elevation snowmelt or monsoon runoff. Evapotranspiration exceeds precipitation by a factor of two in the saltcedar-saltgrass mosaic ecosystem at the Sevilleta (Fig 4). In comparison, the monospecific saltcedar stand at the nearby Bosque del Apache NWR has an ET:PPT ratio of 4:1. Furthermore, there is a strong seasonality to evapotranspiration patterns in saltcedar. Spring-season ET is unresponsive to all but extreme drought in three local ecosystems: saltcedar-saltgrass mosaic (Sevilleta NWR), monospecific saltcedar (Bosque del Apache NWR), and Russian olive (La Joya State Game Refuge). During the summer, ET at the xeroriparian Sevilleta site increased with amelioration of drought. Saltcedar is a facultative phreatophyte in some conditions, able to increase ET following summer precipitation.

An Aqueous Geochemical and Hydrologic Study of the Springs and Wells of the Sevilleta National Wildlife Refuge (A.J. Williams, L.J. Crossey, C.A. Waters (REU)) The purpose of this study is (a) to provide the first hydrochemical data on a comprehensive suite of springs and wells, and (b) to test and refine existing models for water quality in the surface and ground waters within the Sevilleta NWR and the Rio Grande rift. We used hydrochemistry (major, minor and trace [Li, Ba, As] elements,

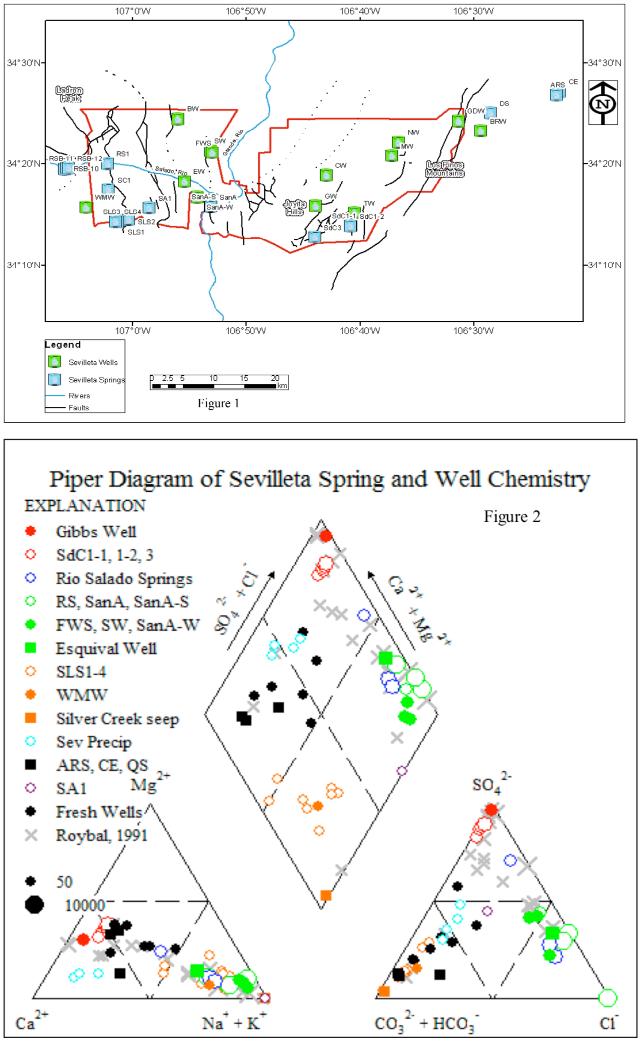


Figure 5. Top Panel: Map of the Sevilleta National Wildlife Refuge showing the location of the springs and wells sampled for hydrogeochemical analyses. Bottom panel: Piper diagram of spring and well water chemistry data.

Cl/Br ratios, $\delta^{18}O$, δD, ^{3}H, and $^{87}Sr/^{86}Sr$ ratios), DNA extraction and characterization of microbes, and geochemical modeling (PHREEQC and Geochemist's Workbench) along a series of transects within the Sevilleta region at the junction of the Albuquerque and Socorro basins (Fig 5). We have expanded the scope of previous spring assessments for the Sevilleta region (Rawling, 2003; Roybal, 1991). An integrated study of spring geochemistry with factors related to poor water quality, such as high SO4, As, and salinity will allow for a better understanding of natural contaminants in the Rio Grande hydrochemical system.

This research was accomplished in collaboration with a Sevilleta 2008 summer REU student (Christine A. Waters, UTEP). A suite of geochemical tracers was used to analyze the geochemistry of 19 spring and surface samples and 13 wells in and near the Sevilleta NWR. We measured pH, temperature, conductivity, and TDS in the field, and analyzed every sample for Na, K, Mg, Ca, HCO_3, F, Cl, Br, NO_3, and SO_4. Continuing studies in the area indicate the interaction of five distinct hydrochemical facies: 1) a **Na-Cl/SO4** composition [San Acacia (SanA), Rio Salado Springs (RSB) and river (RS); Sevilleta (SW), Fish and Wildlife (FWS), Esquival (EW), and San Acacia (SanA-W) wells]; 2) a **mixed cation-HCO3** rich composition [San Lorenzo Springs (SLS1-4), West Mesa Well (WMW), and Silver Creek Seep (SC1)]; 3) a **Ca/Mg-Cl/SO4** composition [Cibola (SdC1-1, 1-2) Spring and Milagro (SdC3) Seep, and Gibbs well (GW)]. The fourth was a **mixed cation/anion** composition [Ojo del Abo (ARS) Spring, Canon Espinoza (CE) Seep, Quarai (QS) Spring, Tomasino (TW), Nunn (NW), McKensie (MW), Goat Draw (GDW), Canyon (CW), and Bronco (BW) wells] and correlates to local precipitation chemistry; and 5) a **Na-mixed anion** composition [Canyon del Ojito (SA1) Spring] (Fig 5). Preliminary stable isotope results indicate a ternary mixing trend between a brine, saline wells, and fresher surface and well waters. Spatially and temporally variant Cl/Br ratios indicate a binary mixing trend between the freshest and most saline sites.

Ecohydrology and clonal growth in grasses (Sujith Ravi, Paolo D'Odorico, Lixin Wang and Scott Collins)

Vegetation patterns such as bands, stripes, spots and rings are a recurrent characteristic of resource limited arid and semiarid landscapes. Interactions between surface soil moisture, erosion processes, and vegetation are thought to be the major factors responsible for the formation of these patterns. The geometry, spatial distribution and scale of vegetation pattern, which result from interactions between biotic and abiotic processes, affect the spatial patterns of soil moisture, sediments and nutrients in these landscapes. The spatial distribution of water and sediments, in turn, determine plant growth, root biomass and species composition. Thus, vegetation patterns can be considered as biological indicators of abiotic processes such as runoff and infiltration, and of source-sink areas for sediments in dryland landscapes. Hence, information on the formation, structure and growth of these vegetation patterns and the analysis of their interactions with abiotic controls can improve our current understanding of important processes underlying the dynamics of arid and semi-arid ecosystems.

To this end, we studied the formation and dynamics of ring growth patterns (Fig 6) by dominant grasses at the Sevilleta LTER (Ravi et al. *in press*). Even though grass ring patterns are observed worldwide, a comprehensive understanding of the biotic and abiotic processes that lead to the formation, growth and breakup of these patterns is still missing.

Figure 6. Example ring growth patterns: *Bouteloua gracilis* (left) and *Muhlenbergia arenicola* (right) at the Sevilleta. These rings are approximately 30-60 cm in diameter.

Therefore, we measured infiltration rates and the physical dimension of grass rings (*Bouteloua gracilis*). Results from the infiltration experiments indicate that infiltration rates are higher at the outer edges of the grass rings compared to the center and interspaces. The difference in infiltration rate between the center and outer edges was larger for small and medium sized rings compared to large rings. The corresponding hydraulic conductivities calculated from the infiltration data showed a similar trend. This pattern is explained by the variations in the fraction of soil fines between the center and outer edges of the grass rings (Fig 7), as soil infiltration is directly related to soil texture. Consistent with previous studies, nutrient content (total C and N) were equal or higher at the center of the rings compared to the outer edges (Fig 7), indicating that nutrient resource depletion was not the reason for grass mortality at the center of the rings. Rather, our results indicate that moisture limitations may explain grass mortality at the center of the rings and soil moisture also may limit ring growth at the outer edges.

From this information we developed a conceptual model of grass ring dynamics. We summarize the dynamics of grass ring development in four relatively distinct stages:

- ***Grass clump***: at this stage an almost uniform clump of grass is surrounded by bare soil. The clump is a preferential microsite for the trapping and deposition of fine wind-borne soil particles. As a result, infiltration rates are lower in the center than at the edges of the clump. Thus, optimal conditions for rainfall infiltration, soil water storage and grass growth are found at the outer edges of the clump.

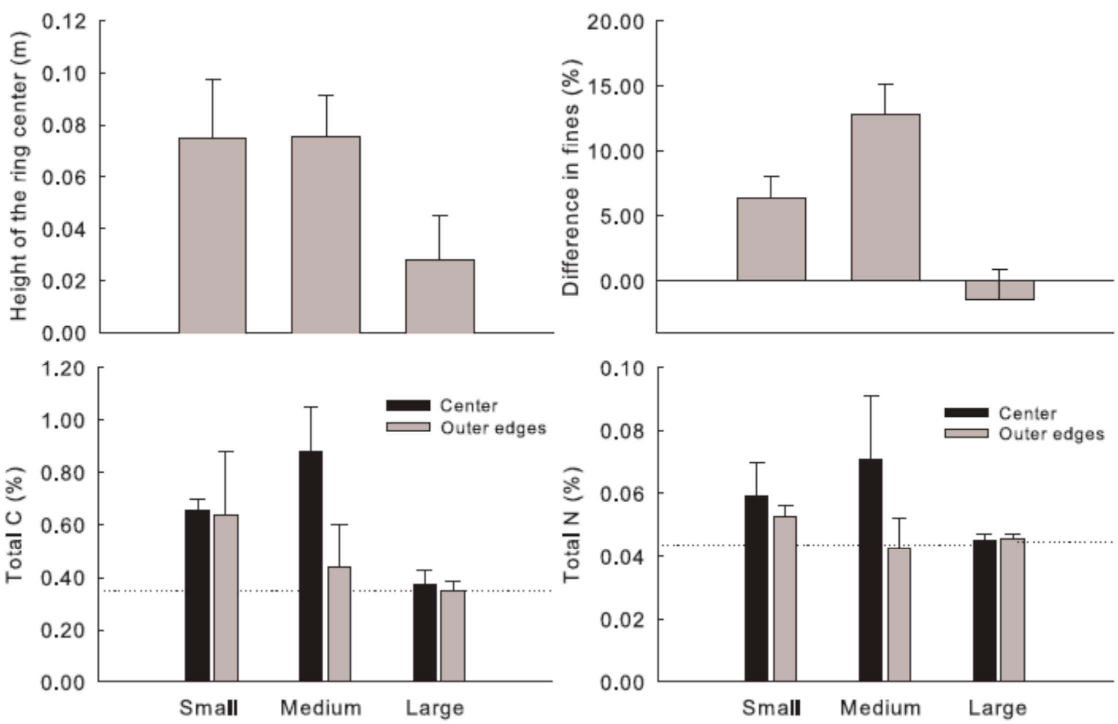


Figure 7. Top, left: Relationship between height and diameter of the grass rings. The error bars represent the standard deviation of height in each size class. Top, right: Difference in fines (clay and silt) between the center and outer edges of grass rings in three ring diameter classes. The error bar represents the standard deviation of the differences in each size class. Bottom: Total carbon (left panel) and total nitrogen (right panel) at the center and outer edges of the medium and large diameter rings. Error bars represent the standard deviation within each size class. The dotted lines represent the average TC and TN of bare soil interspaces.

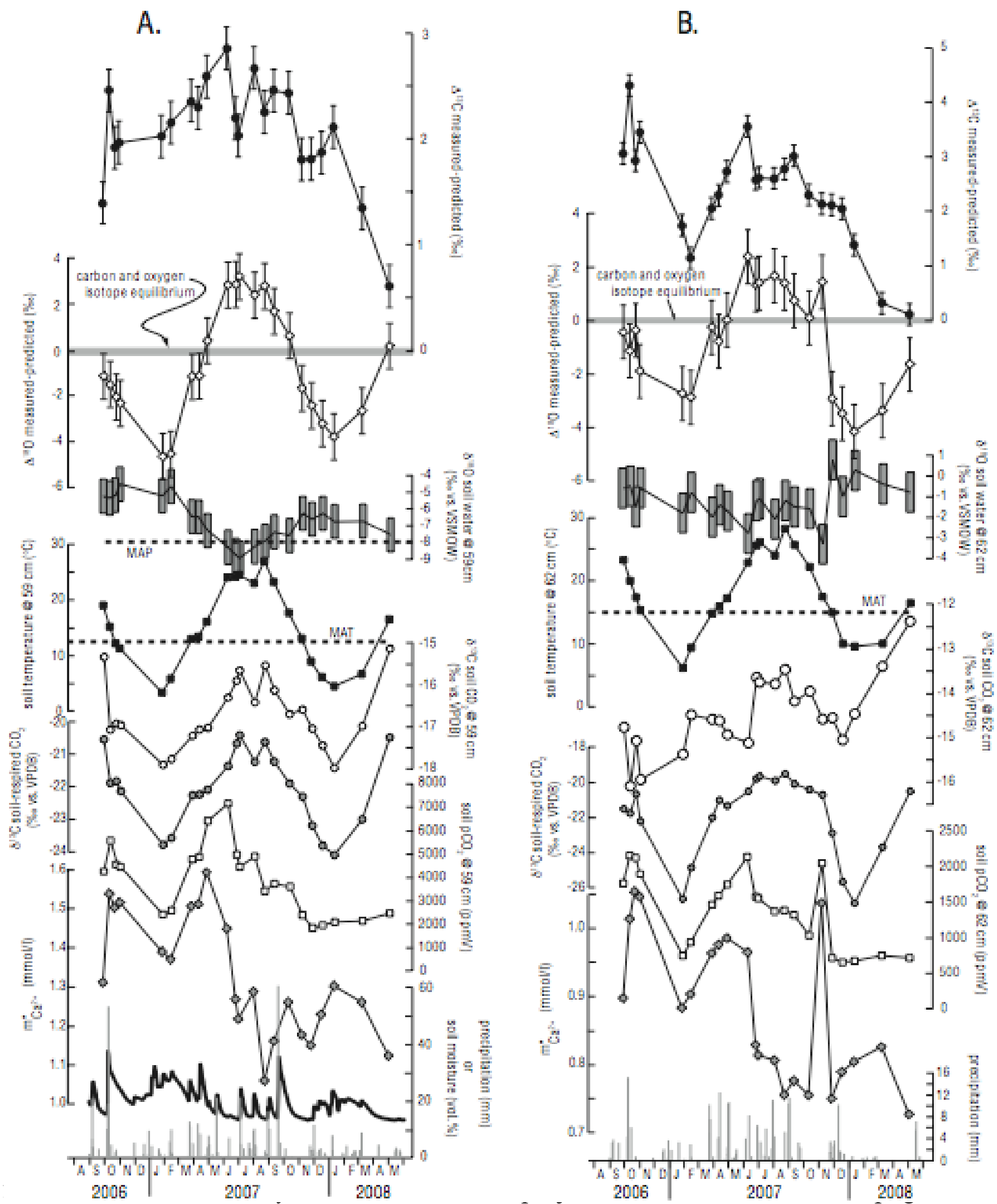
- ***Ring formation***: As the clump radius, r, increases, the grass in the middle of the clump has reduced access to soil water resources at the edge of the clump. Eventually, tillers in the center of the clump die and the soil is exposed.

- ***Early ring stage***. A small to medium-size ring is able to effectively trap and retain fine sediment particles (Figure 4), thereby maintaining low infiltration rates (Figures 2-3), and inhibiting grass growth in the barren soil at the center of the ring. Crust formation may further reduce the infiltration rates and enhance runoff generation in the middle of the ring. Runoff diverges from the center to the (lower elevation) outer edge of the ring, where infiltration occurs. In the absence of a slope the ring expands symmetrically in the direction of the outer edge of the ring, where favorable conditions exist for infiltration and soil water storage, and bud bank formation for future growth (Dalgleish and Hartnett 2006). Due to the limitations in resource availability/accessibility expressed by equation (2), the ring expansion at the outer edge of the ring occurs at the expense 393 of the tillers in the inner side of the ring, similar to the case of tiger-brush banded vegetation.
- ***Late ring stage***. As the ring grows in size its trapping efficiency decreases. The sediments in the middle are less effectively sheltered by the surrounding tillers, and the fine textured bare soil accumulated inside the ring is eroded. Moreover the loss of fine sediments leads to an increase in infiltration rates in the bare soil enclosed by the ring. In these conditions two major processes determining the ecohydrologic functioning of grass rings are either weakened or altered: a) grass growth at the inner edge of the ring is no longer inhibited by limitation in infiltration rates; and b) the effect of runoff concentration from the poorly drained soils in the middle to the outer edges of the rings disappears. As a result the ring becomes less resilient and drought or another type of disturbance may cause the grass ring to break apart. Ring fragments may then serve as nuclei for the formation of new rings, via steps 1 through 4.

Soils (Dan Breecker, Zach Sharp, Les McFadden, Devin Gaugler, Debbie Bryans, Grant Meyer, Nicu-Viorel Atudorei)

Stable isotope composition and soil CO_2 concentrations (Breeker, Sharp, McFadden)
The carbon isotope composition of calcium carbonate formed in fossil soils provides a record of the relative abundance of C_3 versus C_4 vegetation and the concentration of CO_2 in the atmosphere during ancient climates. Soil carbonate has therefore been widely used to reconstruct paleoenvironmental conditions. A careful calibration (using modern soils at the Sev) of the carbon isotope composition of soil carbonate as a vegetation and CO_2 indicator suggests that: 1) soil carbonate is biased toward a C_4 vegetation signal, especially in desert soils and 2) ancient atmospheric CO_2 concentrations were far lower than previously estimated. The C_4 bias originates because carbonate forms in soils during warm, very dry periods when: 1) C_4 plants outperform C_3 plants, 2) photosynthetic discrimination against ^{13}C is minimized (C_3 plants assimilate CO_2 with a higher $\delta^{13}C$ value, closer to that typical of C_4 plants) and 3) low soil respiration rates decrease the proportion of biogenic to atmospheric CO_2 in soils, which increases the $\delta^{13}C$ value of soil CO_2, inducing an artificial C_4 signal that is transferred to carbonate (Fig 8). The reduced estimates of atmospheric CO_2 concentrations also result from the seasonal bias in soil carbonate formation. The new CO_2 estimates for Mesozoic greenhouse climates, resulted

Figure 8. Time series of soil variables. A) P.J. Woodland, B) G.B. Shrubland, C) C.D. shrubland. In the subscripts 'measured-predicted,' measured refers to measured values of pedogenic carbonate and predicted refers to equilibrium carbonate values calculated from measurements of soil CO_2 using measured temperatures. $\delta^{13}C$ values of soil-respired CO_2 were calculated as the concentration of Ca2+ in the soil solution at calcite saturation calculated from measured temperature and soil pCO_2. Error bars on δ18Omeasured-predicted reflect uncertainty of calculated soil water $\delta^{18}O$ values. Symbol size reflects uncertainty for other values. Soil moisture (average of top 30 cm using time domain reflectometry) and precipitation were measured less than 100 m from the P.J. and G.B. Shrubland sites. MAP = mean annual precipitation; MAT = mean annual temperature.



emissions are unmitigated and suggest that long-term equilibrium Earth's surface temperature are twice as sensitive to atmospheric CO_2 as previously thought!

The largest reported variation in the $\delta^{13}C$ value of soil-respired CO_2 ($\delta^{13}C_r$) was observed in Great Basin Shrubland and Chihuahuan Desert Shrubland. Seasonal variation in $\delta^{13}C_r$ of ~8‰ is correlated with vapor pressure deficit and is most likely attributed to changes in photosynthetic discrimination. This work ultimately enables the use of buried soils (or "paleosols") preserved in the geologic record as a high resolution proxy for reconstruction of past biotic communities and paleo atmospheric carbon dioxide concentration, which in turn help elucidate the evolution of Earth and its climate over millions or even billions of years.

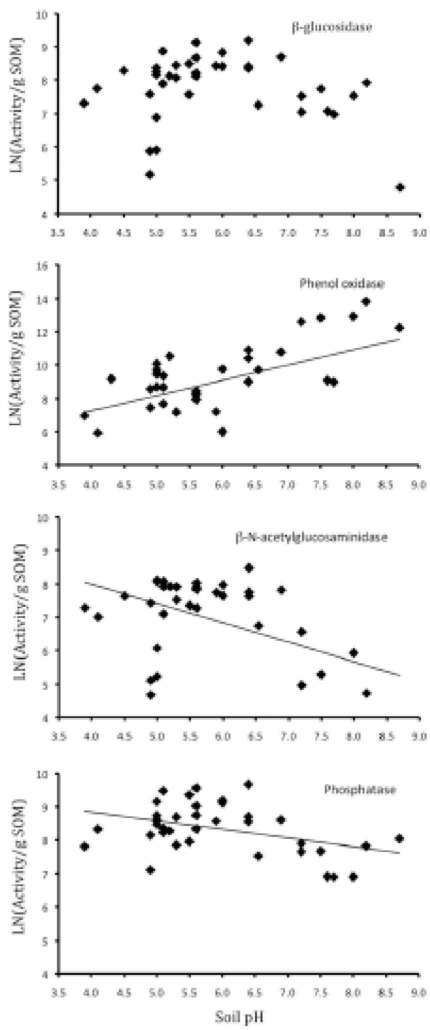
Effects of differential insolation on pedogenesis (Gaugler, McFadden, Sharp) Devin Gaugler, an MS student in the Department of Earth and Planetary Sciences is studying the development of soils on slopes with different aspects in the eastern part of the Sevelleta region, specifically in an area that is characterized by relatively significant incision of older Pleistocene piedmont deposits and/or pediments. The purpose of his research is to characterize the impacts of differenential insolation on weathering and soil development, recognizing the possible influences of different biotic communities present on slopes linked to different aspects and associated topoclimate. Devin's research to date clearly shows that these soils exhibit significant differences in their morphologic expression and solum thickness. Currently, he is conducting a suite of laboratory analyses of the soil materials designed to quantify some of the observed morphological differences to show how soil-forming processes are affected by slope aspect. Key results and preliminary conclusions based on this research will be presented at the Geological Society of America Annual Meetings in Houston, Texas in October 2008.

Complex Polygenesis and Soil Stratigraphy (Debbie Bryans, Les McFadden, Zach Sharp, Grant Meyer, Nicu-Viorel Atudorei). The eastern Sevilleta LTER site presents a unique opportunity to study soils occurring under the same climate regime and at the intersection of three desert bio-zones. Thirteen study sites were located at similar elevation on active Holocene fans of the Los Pinos Mountains, old fans (at least Mid-Pliestocene), and in fill of the Belen Basin of the Rio Grande Rift Zone. The stratigraphy of trenches on young surfaces revealed that the buried soils reflect the patterns of alluvial fan development along the Los Pinos Mountains: 1) younger fans have buried older fans at the mountain front, and 2) young surfaces have not yet been affected by large base level drops associated with the Palo Duro Wash incision. Polygenesis in older soils is linked to climate change and related plant community changes, eolian fluxes, and surface evolution influenced by the Palo Duro Wash incision. The relationships between plant distributions, pH, conductivity, grain size, carbonate content and horizon depth were compared with statistical methods. The results indicate that soil development is unique to each profile and that soil profiles located within a few meters can differ significantly. In younger soils, many properties, such as pH, conductivity, grain size, carbonate content and horizon depth, are correlated with grain size and their distributions change systematically with depth. In contrast, carbonate content, pH and conductivity do not appear to be influenced either by depth or grain size in older soils. Plant distributions are correlated to grain size and to depth to Stage III calcic horizons. Stable isotopes of carbon and oxygen in pedogenic carbonate were also analyzed. The results do not exhibit the depth function observed in other soil profiles. The most negative $\delta^{13}C$ values (0/00 vs. PDB) were obtained from the near surface horizons in all five trench sites.

Biogeochemistry and microbial dynamics (Bob Sinsabaugh, Jose Herrera, Jennifer King, Chelsea Crenshaw, Martina Stursova, Marcy Gallo, Andrea Porras-Alfaro, Laura Green).

Extracellular enzymes are the proximate agents of organic matter decomposition and measures of these activities can be used as indicators of microbial nutrient demand. We conducted a global-scale meta-analysis of the seven-most widely measured soil enzyme activities, using data from 40 ecosystems (Sinsabaugh et al. 2008). The activities of ß-1,4-glucosidase, cellobiohydrolase, ß-1,4-N-acetylglucosaminidase and phosphatase g^{-1} soil increased with organic matter concentration; leucine aminopeptidase, phenol oxidase and peroxidase activities showed no relationship. All activities were significantly related to soil pH. Specific activities, i.e. activity g^{-1} soil organic matter, also varied in relation to soil pH for all enzymes (Fig 9). Relationships with mean annual temperature (MAT) and precipitation (MAP) were generally weak. For hydrolases, ratios of specific C, N and P acquisition activities converged on 1 : 1 : 1 but across ecosystems, the ratio of C : P acquisition was inversely related to MAP and MAT while the ratio of C : N acquisition increased with MAP. Oxidative activities were more variable than hydrolytic activities and increased with soil pH. Our analyses indicate that the enzymatic potential for hydrolyzing the labile components of soil organic matter is tied to substrate availability, soil pH and the stoichiometry of microbial nutrient demand. The enzymatic potential for oxidizing the recalcitrant fractions of soil organic material, which is a proximate control on soil organic matter accumulation, is most strongly related to soil pH. Together these trends result in dramatically different enzyme profiles in aridland soils compared to mesic systems (Fig 10). These trends provide insight into the biogeochemical processes that create global patterns in ecological stoichiometry and organic matter storage.

Figure 9. Natural logarithm of mean extracellular enzyme activity g-1 soil organic matter by site in relation to soil pH.



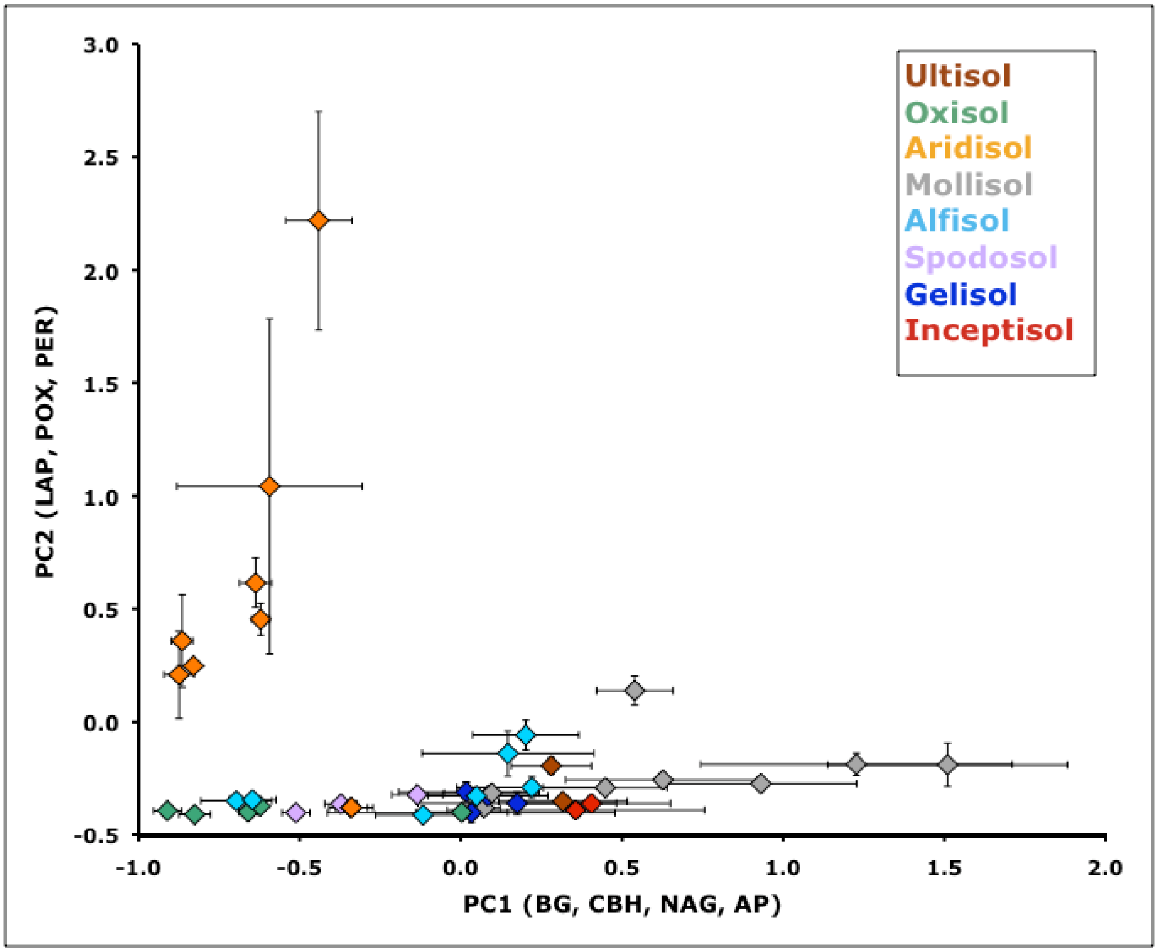


Figure 10. Ordination of 24 ecosystems based on potential soil extracellular enzyme activity g^{-1} organic matter using principal components analysis (varimax rotation). Factor 1 is correlated with BG (r = 0.89), CBH (0.84), NAG (0.92) and AP (0.84). Factor 2 is correlated with LAP (0.85), POX (0.83) and PER (0.74). The vertical grouping represents arid and semiarid ecosystems with soil pH > 7. The horizontal grouping represents ecosystems with relatively high precipitation and soil pH < 7. Values shown are means with 95% confidence intervals.

Producer dynamics in response to disturbances (Deb Peters). Our long-term plant removal study initiated in 1995 is producing interesting results. Our overall objective is to determine which species will dominate following the removal of the current dominant or codominant species. For the two ecotone sites, black grama responded positively to the removal of one of the other co-dominant species, either blue grama or creosotebush (Fig 11). Black grama cover on the removal plots was consistently higher than control plots for most years. Thus, we expect that these plots will shift to black grama dominance in the new future.

However, removal of black grama at these two sites did not result in reciprocal responses by blue grama and creosotebush. Cover of these two species on removal plots was similar to their cover on control plots for all years since 1995 (Fig 12 left panels). These results suggest that black grama is using resources in a different way, either spatially or temporally, and it may be less competitive than the other two dominants such that these species do not respond when these resources are freed up with the removal of black grama. Blue grama and creosotebush appear to already be near their maximum cover in these sites such that an increase is not possible. Sub-shrubs such as snakeweed had the greatest positive response in cover of other species groups (annuals, perennial forbs, perennial grasses) following the removal of black grama at both sites (Fig 12 right panels). More detailed analyses are being conducted to further evaluate the relationships among these co-dominant species and subordinate

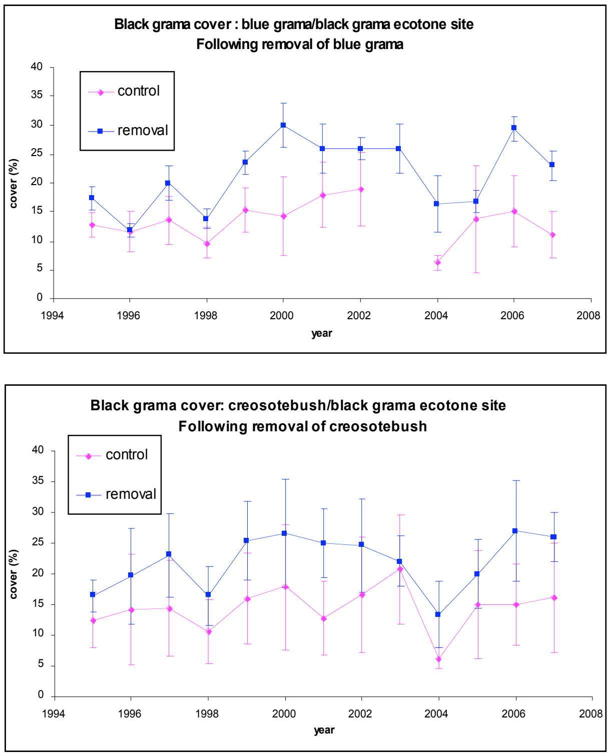
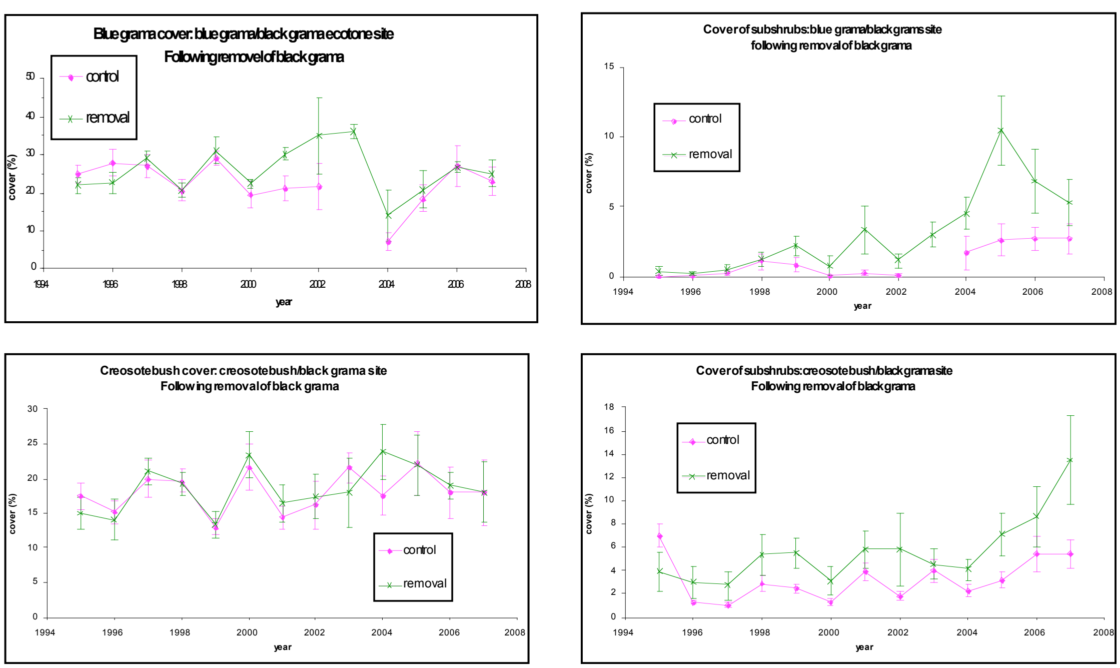


Figure 11. (above) Long-term response of *B. eriopoda* to removal of codominants in grassland and mixed grass-shrub areas.

Figure 12. (below) Long-term response of *B. gracilis* and *Larrea tridentata* to removal of *B. eriopoda.*



species in the different communities.

Cross-site and regional-scale research. We placed the Sevilleta within a regional and continental-scale context (Fig 13) by organizing sites along the Rio Grande Basin within the US (Webfigure 1; Peters et al. 2008). The Sevilleta occurs midway along gradients of temperature (increases from north to south), precipitation (decreases initially then increases to southern Texas), and snowmelt that decreases from north to south (center left panel). Historic patterns of human movement along the Camino Real resulted in the

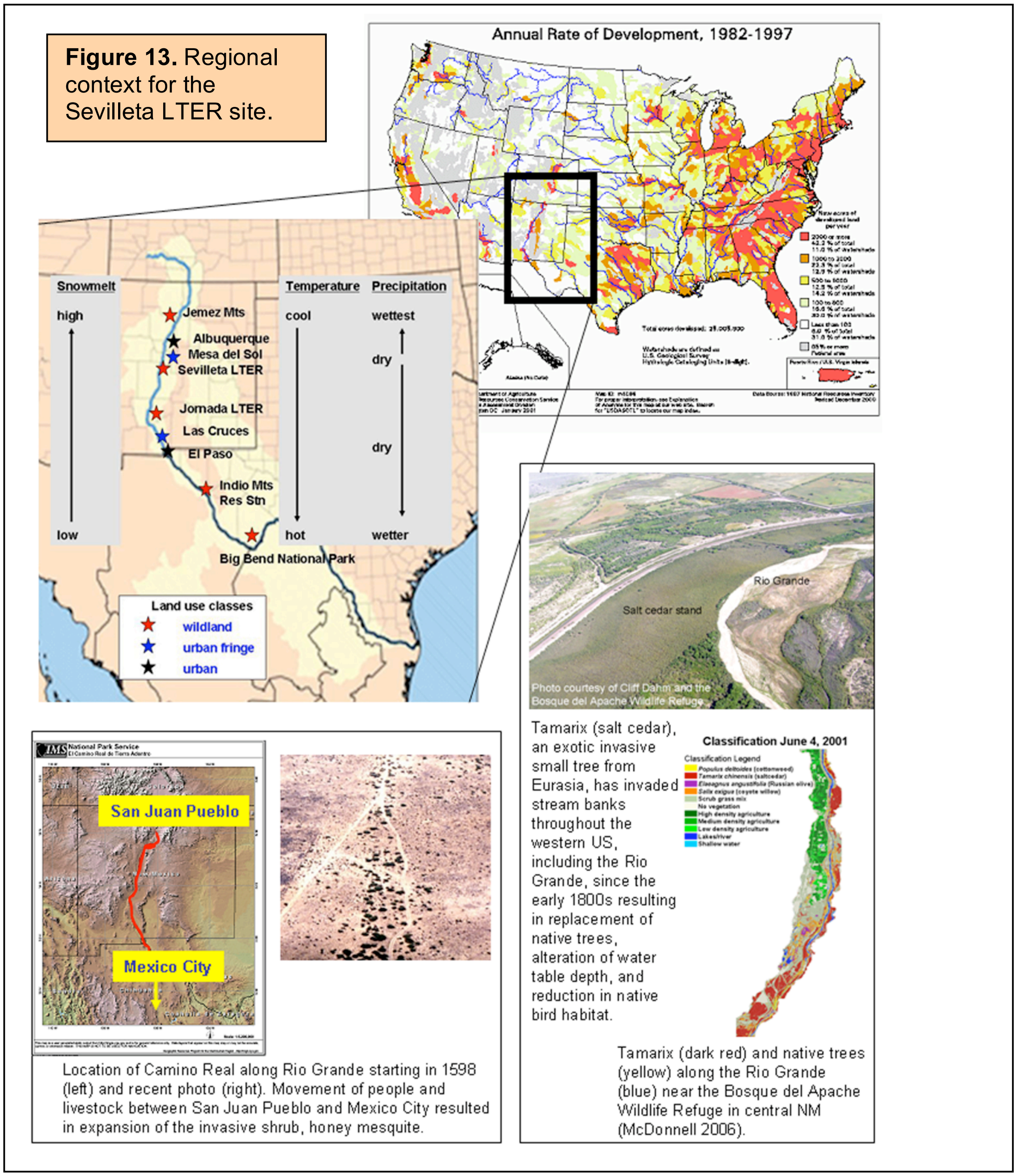


Figure 13. Regional context for the Sevilleta LTER site.

Location of Camino Real along Rio Grande starting in 1598 (left) and recent photo (right). Movement of people and livestock between San Juan Pueblo and Mexico City resulted in expansion of the invasive shrub, honey mesquite.

Tamarix (salt cedar), an exotic invasive small tree from Eurasia, has invaded stream banks throughout the western US, including the Rio Grande, since the early 1800s resulting in replacement of native trees, alteration of water table depth, and reduction in native bird habitat.

Tamarix (dark red) and native trees (yellow) along the Rio Grande (blue) near the Bosque del Apache Wildlife Refuge in central NM (McDonnell 2006).

dispersal of invasive shrubs by cattle along the river. Shrubs then expanded into adjacent desert grassland and connected the river with the desert (bottom left panel). Invasions by salt cedar (Tamarix spp.) over the past 100 years followed stream channels of rivers

(McDonnell 2006) (bottom right panel). Other river basins have a similar hierarchy of patterns (upper right panel). This regional structure is being used by the new ESA Southwest Chapter to organize new and existing research projects, including the NM EPSCoR project.

Net Ecosystem Exchange in desert grassland (Marcy Litvak, John Delong)

Pattern of Net Ecosystem Exchange in desert grassland exhibit high degrees of interannual variability in response to precipitation (Fig 14). For the time periods from Jan 1 to Sept 10 2007 and 2008 this desert grassland served as a small carbon source to the atmosphere: the grassland lost 7 gC m^{-2} during that time period in 2007, and 15 g C m^{-2} in 2008. Precipitation during 189 mm vs. 176 mm in 2007 and 2008, respectively, values close to the long-term average. This information is consistent with our microbial process work that shows very high levels of phenoloxidases and peroxidases in Sevilleta soils (Sursova et al. 2007, Zeglin et al. 2007) indicating that microbes are scavenging for C by breakdown of recalcitrant C compounds. This carbon scavenging limits accumulation of organic matter in these desert soils, making this ecosystem relatively carbon neutral over the long term.

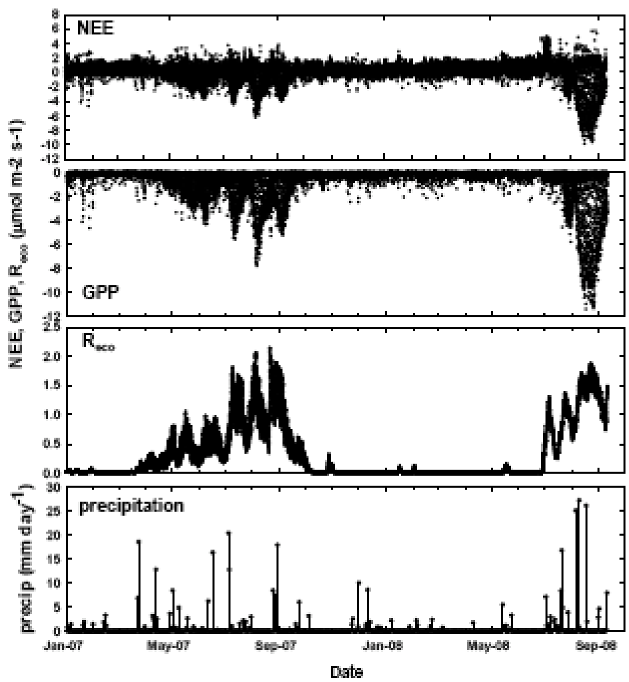


Figure 14. Net ecosystem exchange in desert grassland during 2007 and 2008.

Impacts of drought on Piñon-Juniper woodland (Will Pockman, Nate McDowell, Enrico Yepez, Judson Hill, Jen Plaut, Sue White, Jennifer Johnson, Julie Glaser).

The rainfall manipulation experiment in the piñon-juniper woodlands at the Sevilleta is designed to determine the mechanisms of tree response to chronic drought in this ecosystem. Historical records indicate that the southwestern US is subjected to severe, chronic drought every 50-60 years, perhaps in association with changes in the Pacific Decadal Oscillation (Milne et al. 2003). Regional scale tree mortality occurs in response to these drought cycles, yet the specific mechanisms leading to differential tree mortality between the co-dominants piñon pine (*Pinus edulis*) and one-seeded juniper *(Juniperus monosperma*) are not well understood. In 2006-2007 the Sevilleta LTER initiated a long-term rainfall manipulation study to determine the causes and consequences of tree mortality in response to chronic drought. Treatments include (N=3) ambient plots, plots where annual rainfall is decreased by 50% of ambient, plots where long-term average

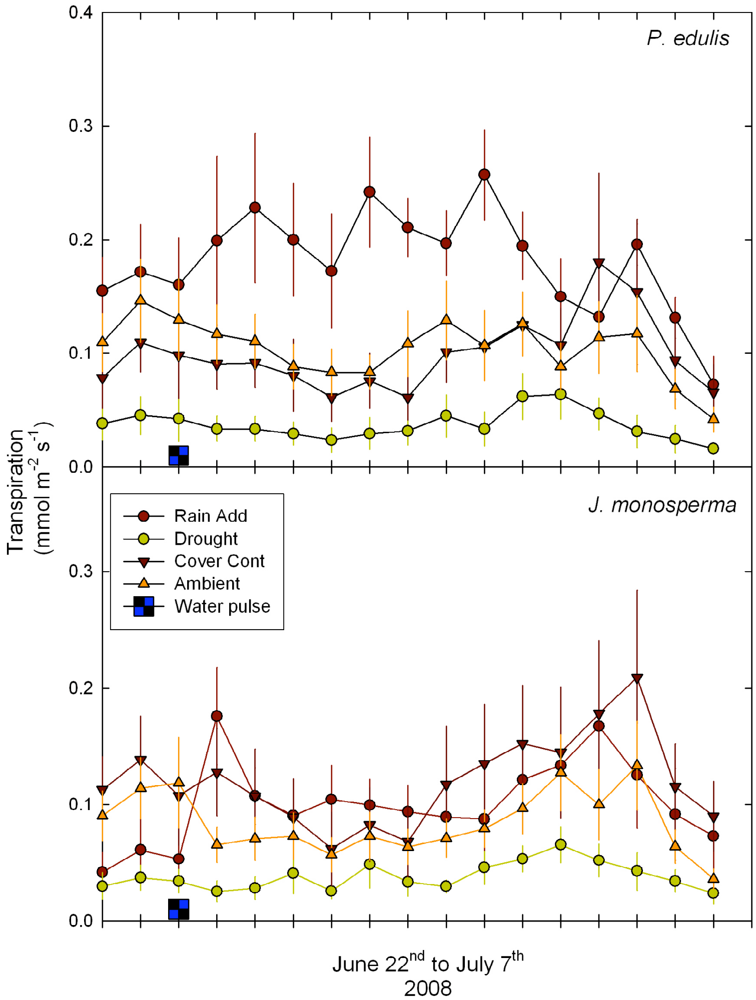


Figure 15. Transpiration rates of piñon and juniper in response to 50% lower rainfall, ambient rainfall, and a pulse irrigation event during June 2008.

rainfall is increased by 50%, and rainfall shelter treatment plots to assess the impacts of the research infrastructure at the site. All plots are 40x40 m. Rainfall reduction started in 2007 and rainfall addition treatments started in the summer of 2008.

Both piñon and juniper reduced their transpiration rates on the drought plots (Fig 15). Responses on cover control and ambient plots are similar suggesting that there is little microclimatic impact of the treatment infrastructure. Both species increased their transpiration rates on plots following a pulse irrigation event in June 2008, with piñon showing higher transpiration rates than juniper.

Plant community response to interannual climate variation (Scott Collins, Yang Xia, Esteban Muldavin, Doug Moore)

Aridland plant communities are strongly driven by seasonal and annual pulses in precipitation. We analyzed a 19-year data set on plant community composition and abundance in response to seasonal and annual precipitation. In addition, we analyzed the ANPP response of desert annuals at our site. Annuals comprise a significant component of plant species diversity in desert plant communities and their composition and abundance varies greatly from one year to the next.

First, plant communities at the Sevilleta are still recovering from the long period of intensive grazing extending from the late 1800's until 1973 when cattle were removed because the property was sold to The Nature Conservancy and then added to the National Wildlife Refuge System. Since 1989 until around 2005, there has been a gradual but consistent increase in the dominant C_4 grasses *Bouteloua eriopoda* and *B. gracilis* and a decrease in the grazing indicator, *Guttierezia sarothrae* in the grasslands south of Deep Well on McKenzie Flats (Fig 16). As expected, there is a strong positive correlation between seasonal rainfall and plant community composition and abundance. In general, the abundance of grasses and forbs during summer increases with summer precipitation and its correlate, summer soil moisture (Fig 17).

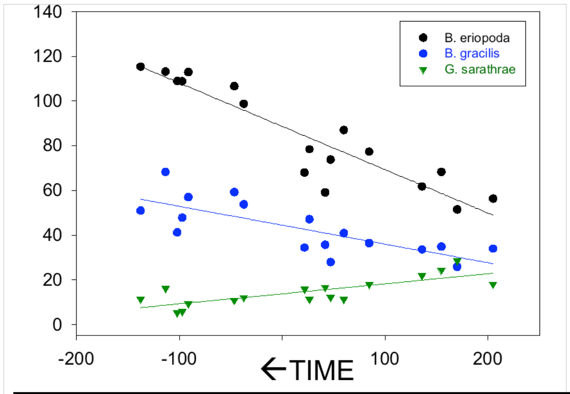


Figure 16. Increase in grass cover and decrease in snakeweed over time at the SNWR. The x-axis is the first axis of a DCA ordination where time goes from right to left. The y-axis is cover of each species in meters out of 400 m total.

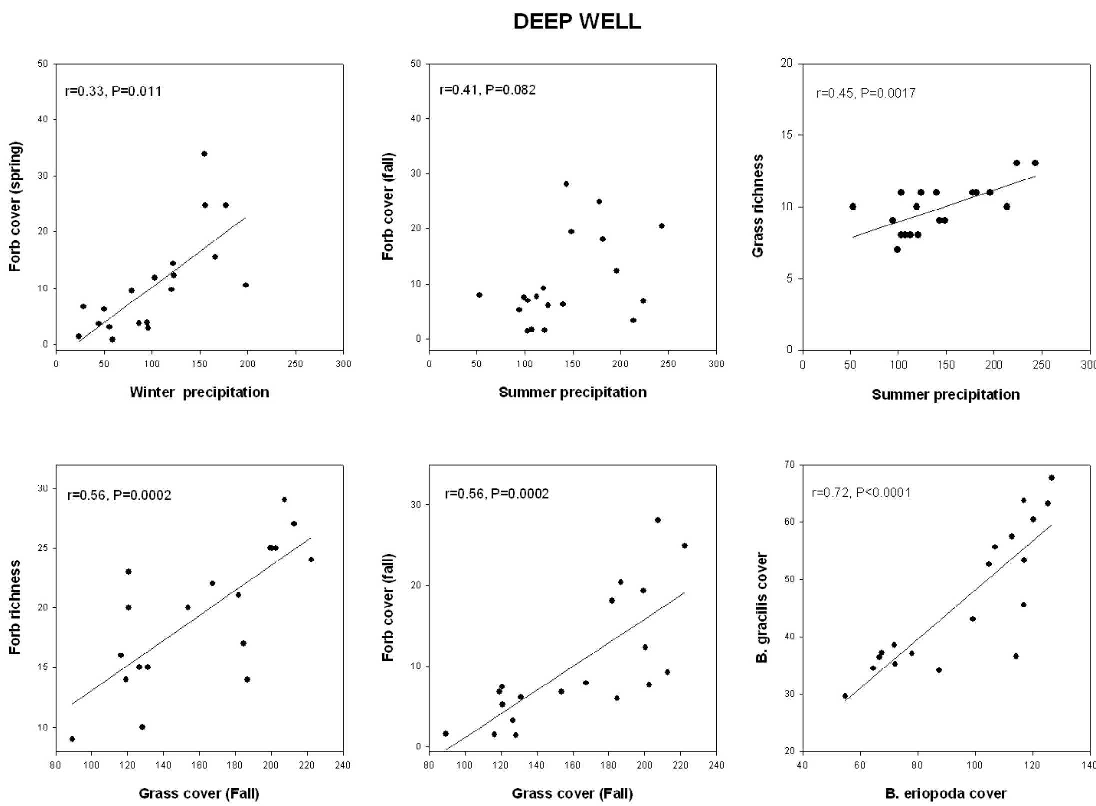


Figure 17. (below) Relationship between seasonal precipitation and abundance of grasses and forbs in desert grassland at Deep Well on McKenzie Flats at the Sevilleta.

Consumer effects on soil seed banks (Terri Koontz, Diane Marshall, Bruce Milne, Heather Simpson)

It is well known that grazers and granivores can have significant top-down effects on aridland plant communities. These effects are mediated commonly through preferential consumption of large vs. small seeds. At the Sevilleta at least one annual species, a weedy native mustard, was found to be more common around active kangaroo rat mounds than in areas away from mounds. We studied the abundance of seeds in the soil seed bank in our Small Mammal Exclosure Study (SMES) site. SMES is a long-term experiment that was initiated in 1995 where fences (n=4 per treatment per plant community) were built to exclude both grazers and granivores from grassland and shrubland plant communities (Fig 18). We analyzed the soil seed bank from the SMES plots to determine the effects of small grazers (rabbits) and granivores (rodents) on the abundance of seeds in the soil seed bank in grassland and shrubland vegetation. These herbivores do not appear to be affecting grassland seed banks; however, when both rabbits and rodents were excluded from the shrubland site, the number of viable seeds in the seed bank was lower (Fig 18). Therefore, grassland vegetation is controlled mainly by abiotic factors such as precipitation; whereas seed predators, such as rodents, may influence plant community composition and dynamics in shrub-dominated vegetation.

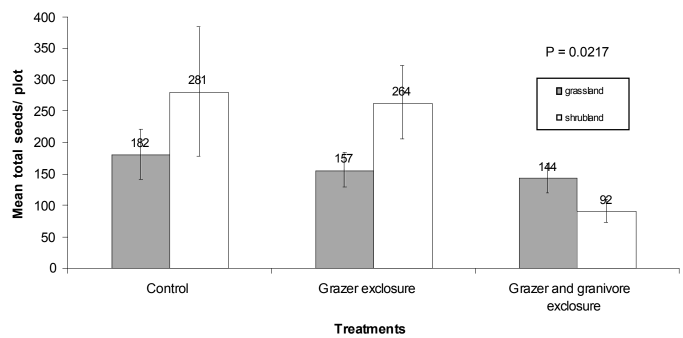


Figure 18. Left: rabbit exclosure (foreground), and small mammal exclosure (background) in grassland vegetation at the Sevilleta.

Trophic structure and dynamics (Blair Wolf, Robin Warne, Alaina Pershall, Sophia Engel, Casey Gilman, Hillary Lease, Nate McDowell)

Understanding resource exploitation by consumers is central to understanding the structure and dynamics of ecosystems at the individual, population and community levels. We are investigating the affects of short and long-term climate variability on the dynamics of carbon flow through a mixed grassland/shrubland food web. At the Sevilleta, winter rains drive the growth of spring annuals and perennials (C_3 photosynthetic pathway) and the summer monsoon drives warm season grasses (largely C_4 photosynthesis) and perennials (Muldavin et al. 2008). Because C_3 and C_4 plants have distinct isotopic signatures of $\delta^{13}C$ we can quantify the proportion of these plants in animal diets through stable isotope analysis. Here we present an expanded analysis of diet specificity of grasshoppers at the Sevilleta.

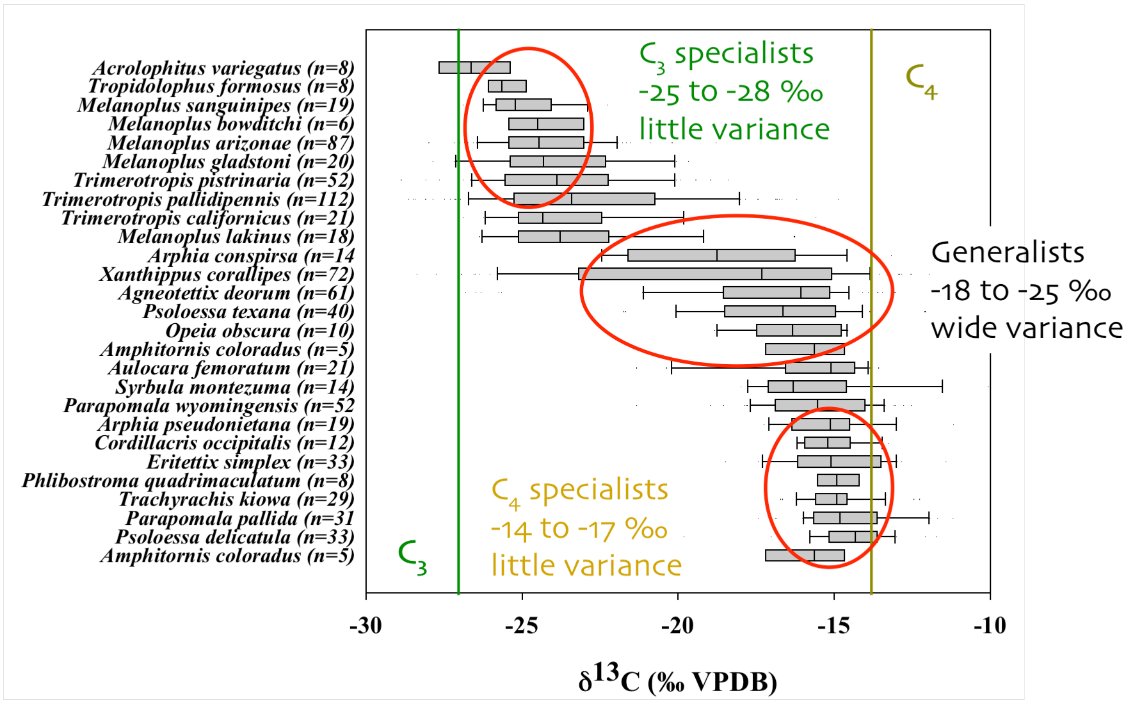


Figure 19. Tunable diode laser absorption spectroscopy was used to generate real-time estimates of grasshopper "breath" $\delta^{13}C$ for 23 to assess the use of C_3 versus C_4 plant resources during the fall of 2006.

We continue to use real-time measurements of grasshopper "breath" $\delta^{13}C$ to estimate the use of C_3 versus C_4 plant resources. We determined the $\delta^{13}C$ of expired "breath" CO_2 of a grasshopper community from the Sevilleta LTER in central New Mexico using tunable diode laser (TDL) absorption spectroscopy (Fig 19). This approach allowed us to quantify the use of specific plant functional groups, as defined by photosynthetic pathway (C_3 or C_4), by grasshoppers of 23 species with body sizes ranging from 0.024g to 9.2 g, and we measured diet shifts over the growing season for several common species at the Sevilleta (Fig 20). Measurements of breath $\delta^{13}C$ show that resource use by the grasshopper community is diverse and includes both generalist and specialist species. We found species that fed only on C_4 grasses, on a mix of C_3 and C_4 plants, and a specialist that fed only on C_3 plant resources (Fig 20). Because our grasshoppers were post-absorptive and thus metabolizing energy stores, breath isotope ratios were correlated closely (R^2 = 0.86) with values from isotopic analysis of body tissues. Plant physiology and thus primary production are tightly coupled to a variety of climate drivers, both in the short and long-term, therefore our approach provides researchers with a tool to directly link consumer nutritional ecology and population dynamics to climate dynamics and explore the influence of these drivers on entire food webs in real-time in the field. As part of this project, RUE's Sophia Engel and Alyssa Corbett examined seasonal shifts in the use of C_3 and C_4 plant functional groups throughout the summer by sampling the community every two weeks and using TDL "breath" analysis.

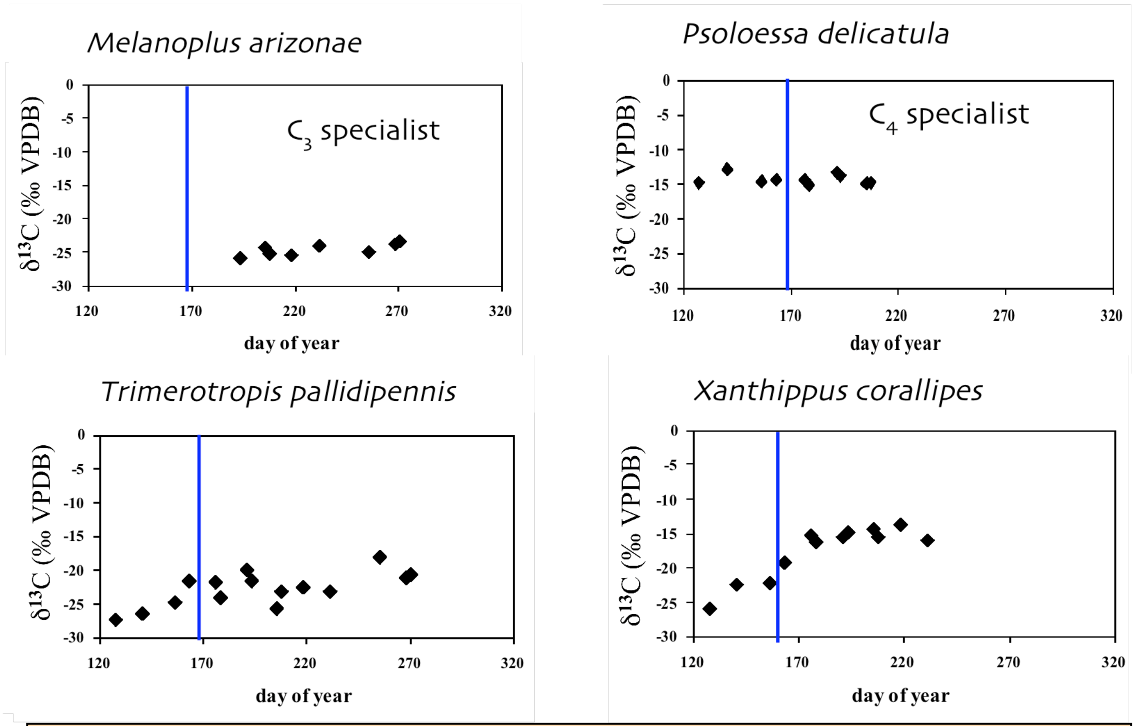


Figure 20. Examples of differences in dietary use patterns among grasshoppers over the growing season using $\delta^{13}C$ values. *Melanoplus arizonae* and *Psoloessa delicatula* are resource specialists regardless of changes in resource availability with precipitation. *Trimerotropis pallidipennis* exhibits some diet shift yet retains strong preferences for a particular resource base. *Xanthippus corallipes* is a diet generalist.

Ant colony size and foraging efficiency in desert grasslands (Melanie Moses, Bill Burnside, Kenneth Letendre, Matthew Fricke and Tatiana Paz).

Ant colonies acquire and allocating food through a network of foragers. Their trail networks, marked with pheromones, channel foragers to known food resources and away from competing colonies. Computer models suggest the spread of information occurs faster in larger colonies of harvester ants, genus *Pogonomyrmex.* Does the ability to utilize and share information scale super-linearly with a colony's size? To address this question, we studied three sympatric species of *Pogonomyrmex* that differ in average colony size: *P. rugosus*, *P. maricopa*, and *P. desertorum*. Colonies were observed at both the Sevilleta LTER and at a vacant block in northeastern Albuquerque. We hypothesized that recruitment to dense food resources scales positively with colony size. We baited active colonies with millet and sesame seeds arranged in piles of different densities. Using a Java program (SeedCounter), we recorded the color and time of each seed retrieved and generated resulting seed uptake curves (Fig 21). We also generated a model of idealized effects of recruitment on foraging patterns and compared the output to our observations. Using colored chalk, we marked ants to track individual foraging trip times.

Results provide some evidence for more-intense recruitment to dense food sources in larger colonies. In *P. rugosus*, the species with the largest colonies, intake rate was greatest for seeds distributed in denser patches. Our analysis showed a similar but less pronounced relationship in the smallest species, *P. desertorum*. In species with larger colonies, average foraging trip times decreased nonlinearly, further suggesting active recruitment. Ant species that share information should be better able to exploit the information content in densely distributed food sources than those that forage singly, providing a benefit for living in larger groups. These findings highlight a key intersection between the metabolism of energy and of information, providing a possible mechanism of differentiation between these related species.

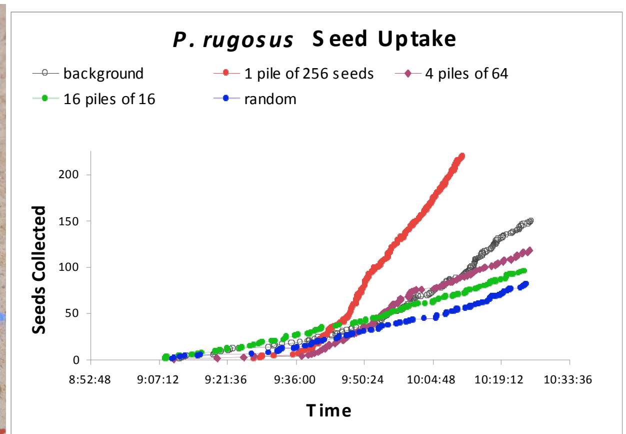


Figure 21. Left: Photo of a marked P. rugosus collecting a seed. Right: Relationship showing more intense recruitment to dense resources by species with larger colonies.

Plant-herbivore interactions in desert grasslands. (T.E.X. Miller)

My research at the Sevilleta LTER focuses on the ecological and evolutionary dynamics of plants and the insects that eat them. The broad objectives of this work are to understand the sources of temporal and spatial variation in plant-herbivore interactions, and the consequences of this variation for individual fitness and population dynamics. As an empirical model, my research focuses on cacti (*Opuntia* spp.) and cactus-associated arthropods (herbivores, predators, and mutualists), a study system rich in interesting natural histories and ecologically important interactions.

My recent findings at the Sevilleta LTER highlight the key roles of arthropod consumers in plant life history evolution and population dynamics. First, I found that damage by cactus-feeding insects increased in response to plant reproductive effort (proportional allocation of resources to flowers; Miller et al. 2006, Miller 2007). The relationship between floral allocation and insect damage imposed an herbivore-mediated, “ecological” cost of plant reproduction. Optimality models indicated that such ecological costs of reproduction can strongly influence the evolution of plant life history strategies (Miller et al. 2008). Second, I found that herbivorous insects depressed the rate of cactus population growth, and that spatial variation in herbivory was a driver of variation in plant abundance across a grassland-mountain elevational gradient at the Sevilleta LTER (Fig 22). This project, which integrates long-term insect exclusion experiments with size-structured demographic models, has provided new insights into the effects of consumers on the distribution and abundance of long-lived plants (Miller et al. *in press*).

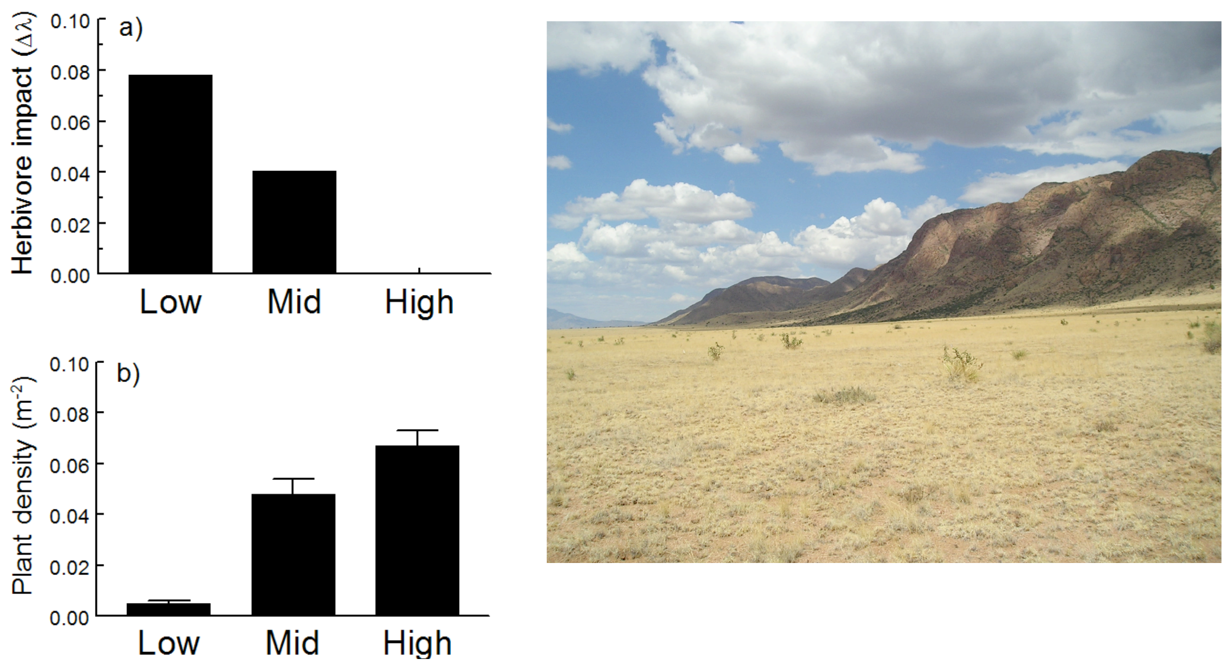


Figure 22. Effects of insect exclusion on (a) cactus population growth ($\lambda_{Exclusion}$ - $\lambda_{Control}$) and (b) cactus density in three zones along a grassland-mountain elevational gradient (see photo). The inverse relationship (a,b) implicates insect herbivores in the pattern of plant distribution.