

Sevilleta Long-Term Ecological Research Program: Measuring Ecosystem Responses to Environmental Change

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Abstract—The purpose of this paper is to describe the research program of the Sevilleta Long-Term Ecological Research Program (LTER) at the University of New Mexico. Details and data for each of the research topics described can be found in the Sevilleta LTER Internet Homepage (<http://sevilleta.unm.edu>).

The Sevilleta LTER Program is conducted by the University of New Mexico's Department of Biology in close collaboration with the U.S. Fish and Wildlife Service, and is funded by a major grant from the National Science Foundation. The Sevilleta LTER is part of a coordinated network of 21 LTER sites that span North America (including two sites in Antarctica). The Sevilleta LTER Program concentrates its research efforts on the Rio Grande Basin in central New Mexico.

The Sevilleta Long-Term Ecological Research Program (LTER) was initiated in October, 1988, and has focused on a suite of ecological hypotheses concerning climate dynamics and the responses of organisms in a biome transition zone in central New Mexico. The Sevilleta LTER research region straddles several major biomes of the Southwest, and the large geographic scale of the Sevilleta region is important for studies that range from genetics and physiology at the organismal level, to the dynamics of biome transition zones. The region is strongly influenced by the El Niño Southern Oscillation (ENSO), with major fluctuations in precipitation on semi-decadal time scales.

Under the Sevilleta LTER program, mathematical water balance models are providing a unifying synthesis of the LTER core topics and the various levels of organization studied by the participating investigators. The water balance approach takes advantage of continued studies from 1988-1994 (for example, vegetation, climate data, precipitation estimation from lightning, other GIS data, and remotely sensed imagery) and provides a conceptual and quantitative context for a number of new studies that provide a richer and more complete characterization of the Sevilleta region. In addition, LTER scientists will implement a systems model of the CENTURY class in a geographical context, in which the water balance will be driven by the nonequilibrium water model. Thus, the models will provide a synthesis of existing

and future data concerning the core areas of organic matter processing, primary production, and inorganic inputs. The synthesis will be of immediate use in relation to the disturbance and population core topics, including vegetation-environment relations, nutrient dynamics, species distributions and abundances, animal population studies, and population genetics. These field and laboratory studies will provide the necessary biological components that represent the contingencies and feedbacks that are both the responses to, and the constraints on, the dynamics of water.

Site Description

The University of New Mexico's Sevilleta Long-Term Ecological Research Program (LTER) in the central Rio Grande Basin is part of a National Science Foundation network of research sites that examines the responses of ecosystems to environmental changes. The Sevilleta LTER Program is located primarily at the Sevilleta National Wildlife Refuge (Socorro County, NM), but researchers also utilize areas in Cibola National Forest, Bosque del Apache National Wildlife Refuge, El Malpais National Monument, Bandelier National Monument, Los Alamos National Laboratory, Pecos National Historical Park, Petroglyphs National Monument, Kirtland Air Force Base, and the USAF Melrose Range. These varied study sites include a wide range of ecosystem types, including Chihuahuan Desert, Great Plains Grassland, Colorado Plateau Shrub-Steppe, Pinon-Juniper Woodland, Bosque Riparian Forests and Wetlands, Ponderosa Pine Forests, Mixed-Conifer Montane Forests, and Subalpine Forests and Meadows. The dominant theme of the Sevilleta LTER Program is to examine long-term changes in ecosystem attributes (for example, population dynamics of plants and animals, nutrient cycling, hydrology, productivity, species diversity) as a result of both natural and man-made disturbances (for example, global warming, acid rain, grazing, wildfires, droughts, and the "El Niño—Southern Oscillation" (ENSO)). Through these long-term studies, scientists will improve their understanding of the natural dynamics of ecosystems in the heterogeneous landscape of central New Mexico.

Sevilleta LTER: A Regional Research Program

The Sevilleta research region spans the Rio Grande Basin. In the Socorro County area, study site elevations range from 1,350 m at the Rio Grande to 2,195 m in the Los Pinos Mountains in the east, to 2,797 m at Ladone Peak in the northwest, and to 3,450 m in the Magdalena Mountains to

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the southwest. Other important regional features include the San Agustin Plains to the west, and the Jornada del Muerto ("Journey of Death") valley to the south. The San Agustin Plains is an ancient lakebed, which has had a number of paleoecological studies that have characterized the long-term vegetation changes in the region; it is also the site of the Very Large Array Radiotelescope funded by NSF. The Jornada del Muerto extends southward some 125 km, and is largely uninhabited except for military personnel at the White Sands Missile Range, site of the first atomic bomb test. The Jornada del Muerto area is the northward extension of habitats characteristic of the Jornada LTER.

Variations in elevation, parent material and geomorphic setting have combined to produce a variety of soils and habitats ranging from thin and rocky residual soils to deep alluvium. For example, in the Sevilleta NWR outside of the floodplain, there are 3 orders, 6 suborders, 10 great groups, 17 subgroups, and 38 named series of soils represented. In the floodplain are additional Entisols and Vertisols. The variability attributed to topography, geology, and soils over a number of scales contributes directly to the variety of gradients in the region. There are wide ranges of variation in soil properties such as texture, depth, presence of argillic and calcic horizons, A-horizon organic matter content, temperature and moisture regimes, and salinity.

The imposition of climatic dynamics in combination with diverse microsite characteristics presents numerous, excellent opportunities for research on species and ecosystem dynamics. Climatic dynamics occur over a range of time and space scales and the research region offers an opportunity to examine many of them. There is a rich set of "behaviors" in response to the dynamics of climate. At one end of the spectrum, areas as large as the Sevilleta or Magdalena Mountains can be viewed as a single pixel and will show variations in spectral reflectance from seasonal to annual time-scales and longer. At another point in the spectrum, species are subject to genetic change and demonstrate an evolutionary response to climate dynamics, at both fine and broad scales. In between these examples is a rich diversity of biological and ecological features that can be studied. The current research ranges from studies of genes to landscapes.

Although the dedicated research areas form the core of the site research, there are excellent opportunities to evaluate management influences on species or landscapes. Intensive grazing occurs outside the boundaries of the research areas and fence-line contrasts have been studied frequently. The Rio Grande provides irrigation water, and floodplain agriculture also has been studied. The juxtaposition of reserved and managed areas also allows studies of, for example, species' refuges, dispersal factors, the influence of exotics, and disturbed-land restoration.

LTER in a Biome Transition Zone

Topography, geology, soils, and hydrology, interacting with major air mass dynamics, provide a spatial and temporal template that has resulted in the region being a transition zone for a number of biomes. The region contains communities representative of, and at the intersection of, Great Plains Grassland, Colorado Plateau Shrub-steppe,

Chihuahuan Desert, Interior Chaparral, and Montane Coniferous Forest. The elevational gradient of the Magdalena Mountains provides further transitions for Interior Chaparral, Pinon-Juniper Woodland, Montane Conifer Forest, Subalpine Conifer Forest, and Subalpine Grassland. The Magdalena Mountains represent the northeastern limit of Interior Chaparral and are unique in having both Subalpine Conifer Forest and Interior Chaparral on the same mountain range.

The regional location at the junction of a number of biomes is critical for quantifying (1) gradient relationships with distance, (2) the scale-dependent or independent nature of spatial variability, (3) how steep gradients influence system properties, (4) integrated responses across the region, and (5) biome responses to climate change.

Biodiversity

The size of the area, the heterogeneous topographic and geological features, and the characteristics of a biome transition zone have resulted in a rich diversity of species. At least 104 families, 1,201 species and 208 varieties of plants occur within the study region, and many species are at their distributional limits. For example, 54 plant species terminate their geographic distributions within the Sevilleta NWR. Some of these species represent major life forms and physiologies, such as the C3 perennial grasses (*Oryzopsis*). The terrestrial vertebrate fauna includes 89 species of mammals, 353 birds, 58 reptiles, and 15 amphibians. A substantial proportion of these species have a geographic distribution boundary within the region. Reptiles provide the most dramatic example, as 47 of the 58 species end their distributions in the vicinity of the Sevilleta (33 of these are northern limits of desert species). In addition, a high diversity of ground-dwelling arthropods, with distinctive habitat-specific assemblages, has been documented in recent and ongoing studies.

An important feature of the biodiversity of this region is the number of examples of sympatric swarms of closely related species. This sympatry affords opportunities for studying the evolutionary differentiation of species. For example, six species of mice in the genus *Peromyscus* occur on the Sevilleta (a seventh may also occur), of which five have been found coexisting on a one hectare plot. Four species of *Bouteloua* grasses can be found in the same habitat, and seven species of lizards in the genus *Cnemidophorus* are present. Six of these seven lizard species are found in Sevilleta shrubland habitats, and all seven are present in the shrubland/pinon-juniper transition.

LTER Program as an "Ecological VLA"

At a regional scale, the central New Mexico landscape is composed of a mosaic of biome types, many of which are represented by study sites in the Sevilleta LTER. The study region also straddles the boundary between major seasonal air masses (for example, the "Arctic express" on the Great Plains influences Sevilleta's eastern edge; Great Basin polar air masses extend to Sevilleta's northern edge; the Bermuda High generates summer convective storms over

the mountains, which track northeast across Sevilleta's lowlands). Superimposed on these spatial patterns are the temporal dynamics of the ENSO phenomenon. These climate phenomena are a function of orographic effects of the southern Rocky Mountains and the New Mexico basin-and-range topography.

Given the reasonably large latitudinal, longitudinal and elevational gradients found in the Sevilleta study region, Sevilleta LTER researchers have access to many representative biome "patches" that lie close to the edges of their continental distributions. The LTER capitalizes on this "biome diversity" to scale-up the population, community and ecosystem studies, and address biotic responses to climate change on a regional basis. To accomplish this, we have developed an ecological analog to NSF's Very Large Array Radiotelescope (VLA). The VLA is composed of a series of scattered, individual dish-antennae, that, when monitored simultaneously, reveal high-resolution data on obscure astronomical objects. As a rule, signal resolution increases with greater antennae numbers and spread-diameters.

In line with this approach, the LTER Program established a number of research sites (VLA antennae analogs) in various habitats ranging from Rio Grande riparian forest through grassland, shrub-steppe, desert shrubland, pinon-juniper woodland, mixed-conifer subalpine forest, and subalpine meadow. In combination with the Sevilleta LTER Program, the studies at Bosque del Apache NWR, Cibola National Forest, Kirtland Air Force Base, and four National Monuments are becoming important components of the New Mexico "Ecological VLA." With this network of sites, that spans a two-fold gradient in precipitation amount (VLA spread-diameter analog), we can address problems that require simultaneously-measured, multi-biome data. Such topics include the role of drought or wet cycles on (1) primary production, decomposition and nutrient cycling budgets at a regional scale, (2) species diversities and trophic structures of biotic assemblages across landscapes, and (3) population dynamics and demographics of plants and animals with multi-biome distributions. The benefit of this approach is enhanced greatly by the fact that all these regional research sites are subjected to the same regional climate dynamics; for example, a drought year for one site is a drought year for all. With the ecological VLA approach, the LTER Program can conduct a "natural experiment," examining proportionate or disproportionate responses of biome types under a similar climatic "treatment."

Hypotheses Addressed by the LTER Program

The LTER Program addresses a number of ecological questions, including: 1) How do the El Niño/La Niña climate dynamics influence ecological processes, such as nutrient cycling and energy flows, as well as the population abundances and spatial/temporal distributions of plants and animals; 2) What effects do climate dynamics have on the species compositions and trophic structures of the various biome types; 3) Across the central New Mexico landscape mosaic, are there similar or disproportionate responses among communities in various biome types when subjected to a common, regional climate change (for example, drought);

4) Are patterns of plant and animal demographics, density/abundance, survivorship, and reproduction associated with habitat-specific variables (for example, primary production, precipitation, soil moisture, temperature); 5) How does the heterogeneity of habitat mosaics, in concert with their ecotones, influence floral and faunal distributions, and which species might be poised for habitat invasion/retreat following abrupt or long-term climate changes?

Project Description

The following provides a conceptual description of the Sevilleta research program's present status and future direction, based largely on current trends and national funding priorities in ecological research. Following this section is a more detailed projection of the long-term future of the Sevilleta LTER Program.

The primary values of the research region include: (1) the dedicated research areas occupying a large area (150,000 ha), (2) the location at transitions spanning a number of biomes, and (3) the high biological and environmental diversity. The transitions can express themselves in a number of ways, as various gradients of soils, geology, and topography change through space and time. Climate change will also express itself over a range of time and space scales and the ecological transitions of the Sevilleta region represent an opportunity to examine many of them. We anticipate that the area will demonstrate a wide range of "behaviors" in response to the dynamics of climate. For example, the 1950's drought caused marked vegetation boundary movement in much of the region. The 1988-89 La Niña event produced a strong winter drought that prevented spring production of C3 grasses. Other wet years in the early 1990's caused increased production and expansion of C3 perennial grasses (*Oryzopsis*). The area is expected to provide a rich set of ecological "tools" capable of quantifying the range of responses to environmental dynamics.

The high biodiversity is related to the large area, heterogeneous habitats and the transitional area for so many biomes. This offers excellent possibilities to understand the factors that contribute to the high diversity, including the high degree of sympatry for closely related species. Population studies are focusing on the interaction between climate change and evolutionary change. Climate change may both stretch the limits of response and change the process of evolution through climate-induced changes in population structure. The effects of a dynamic and heterogeneous environment are expected to be magnified for species at the margins of their ranges. Such species, near the limits of physiological tolerance, are most likely to be affected by short time scale changes, and their population dynamics may reflect the rapid environmental changes typical of this region.

Disturbance patterns and frequencies are important forcing functions for the ecology of the area. "Disturbance" is viewed and studied across many scales that range from antelope hoof-marks in the soil crust between plants, to individual plant mortality (gap dynamics), to mammal mound activity, to frequency and intensity of flooding/scouring in ephemeral streams, to the grassland and forest fires that are increasing in frequency in the protected areas, and to decadal patterns of climate dynamics.

Landscape dynamics also receive significant attention. The hundreds of square kilometers surrounding the Sevilleta Field Station provide a natural laboratory for studying the interplay between temporal environmental variation and the spatial patterning of habitat. Viewed from afar, the extensive landscape exhibits repeating patterns of low-elevation grassy plains punctuated by ascending topography that may be viewed as a superstructure upon which environmental gradients are arrayed. As precipitation and temperature vary temporally, we expect to see spatially correlated shifts in the distributions of habitats, and consequently species distributions may be envisioned as ever expanding and contracting mosaics constrained by the shifting habitats. An interesting analogy between the landscape dynamics and the annealing of alloys provides a theoretical framework for the envisioned fluctuations. Annealing is the process of repeated heating and cooling of mixtures. Heating excites the component molecular species to seek new configurations that result in minimized free energy levels upon cooling. Variation in annual precipitation constitutes an "excitation" of the system, thereby allowing the entire collection of species to seek new "free energy levels" which may be characterized by such measures as genetic similarity, species richness (per area), primary production, or by multivariate vectors of community composition. The free energy achieved depends on the organismal, demographic, community, and ecosystem level interactions of the populations involved.

Restoration biology also is an area of intense interest in the region. The grassland and desert shrub areas of most of New Mexico were heavily grazed for centuries. The research areas allow experiments and studies of natural succession and recovery. Species reintroductions also are being planned, such as the native Desert Bighorn Sheep in the Sierra Ladrones and pronghorn antelope on the Sevilleta NWR west of the Rio Grande. The riparian cottonwood forest along the Rio Grande also has been greatly altered by harvesting, river control from impoundments, and invasion by exotics. UNM and FWS ecologists have initiated a new research program at Bosque del Apache NWR that examines aspects of cottonwood forest restoration, focusing particularly on flood manipulations of the Rio Grande and the effects on riparian forest ecosystem processes.

Summary of "Core" Program Studies

The Sevilleta LTER Program is an integral part of the regional research effort, and has already proven to be a tremendous asset to both resident and visiting research scientists. The "long-term" nature of the LTER funding schedule (6-yr intervals) contributes a large degree of continuity and stability to the region's research program, ensuring consistent collections of important "core" data sets. The following sections summarize the various ecological research programs that continually accumulate these "core" data sets, all of which are accessible to any interested scientist. The existence of these ongoing projects greatly enhances the data bases available to scientists during all phases of project implementation, from hypothesis development and experimental design through data analysis and interpretation. The LTER "core" projects take advantage of the region's large size and valuable characteristics as a

biome transition zone. The approaches are designed to emphasize a variety of scales and levels, including landscapes, phenotypic plasticity, and evolution. Numerous other ongoing studies in geology, anthropology, hydrology and geomorphology will not be discussed because of space limitations.

Meteorological Studies

The Sevilleta NWR has been instrumented with 7 fully-equipped meteorological stations and data-loggers, over 50 rain gauges, and an additional 20 collectors for precipitation chemical analysis. The Langmuir Laboratory is also equipped with meteorological stations. Historical weather records (100+ yr) for the region are available from the Socorro, NM, weather station. The LTER also acquires lightning strike data (frequencies and locations) for the entire central New Mexico region. All weather data are archived in the Sevilleta Information Management System (SIMS), and are available on request.

Vegetation Assemblage Studies

The principal, large-scale environmental gradients are related to the north-south and east-west characteristics of meteorologic dynamics and topography. Major transects 3 km wide, 30 to 50 km long are designed to traverse the transitions between biome types as well as maximize or minimize environmental gradients (for example, temperature and precipitation) and elevation. Transects of this scale allow remote sensing analyses from aircraft and satellite to be coordinated with balloon photography and ground truthing to identify gradients in spectral reflectance, species distributions, and substrates. Within the transects, 1 km² plots concentrate traditional plant (as well as animal) measurements and permanent photography quadrats.

Watershed Studies

The justifications for including a watershed approach within the region are: (1) water courses amplify variation in precipitation, especially in arid and semiarid regions where there is a nonlinear relationship between variation in precipitation and variation in runoff. Hence, biological responses (demographic, functional, etc.) to changes in mean climate will be magnified along ephemeral watercourses; (2) drainage networks have a natural, hierarchical organization and scale by both size and dynamical behavior, with the smallest watersheds flowing at high frequency and low magnitude and large watersheds at low frequency and high magnitude (Yair 1983, Yair and Shachak 1982); (3) watershed studies have, as a central focus, movement of water across the landscape (the focal constraint in the region's ecology), and represent especially steep, spatially predictable, gradients in water availability; and (4) watershed-based analyses allow comparative studies with other research environments. The watershed studies are based on a conceptual view of watershed processes developed in the Negev Desert. The focus is on biotic responses to the hydrologic redistribution of water as a consequence of interaction between scale, climate, local geology, and microtopography.

These interactions result in spatially predictable patterns of average runoff intensity and frequency. During the last ten years, eight ephemeral stream sites nested within the Rio Salado drainage have been studied with watershed areas spanning several orders of magnitude (4 at about 22 ha, 2 at 240 ha, 1 at 3,000 ha, 1 at 300,000 ha). The hydrologic data of U.S.G.S. for the Rio Puerco (1 million ha) and the Rio Grande (5.5 million ha) provide long-term, broad scale results. Recent studies of El Niño/La Niña effects in the region also identify temporal predictability at certain scales. The watershed studies (1) form a model for studies of other constraints which change across scales in other landscapes, and (2) form an empirical basis in attempts to link ecological studies to regional and global biogeospheric studies.

Plant and Animal Population Studies

For plant population studies, the ideas focus on the interaction between climatic change and evolutionary change. Climate change may both stretch the limits of response and change the process of evolution through climate-induced changes in population structure. For long-lived species, it is crucial to understand the limits of phenotypic response. For shorter lived species, genetic change is possible. The effects of short term climatic change on the evolutionary process is being studied by investigating the effects of La Niña and El Niño conditions on gene flow and reproduction in current populations.

Plant productivity responses to environmental dynamics may change beyond simple responses to climate due to enhanced susceptibility to herbivores. Monitoring specific interactions between a plant species and its herbivores show at what levels plants react initially to climate change. Genetic variation of spatially separated populations and changes in response to changing environment as well as altered herbivore interactions are hypothesized to control landscape patterns of species.

For animal populations, movement of individuals is being quantified, as well as dynamics of populations, abundance and distribution of species, and trophic and taxonomic composition of assemblages of mammals (rodents, rabbits, coyotes), birds, and surface-active arthropods. Patterns and rates of genetic change (in isozymes and mitochondrial DNA clones) are monitored in rodents. These measurements are made over a sufficient range of spatial and temporal scales: (1) to document the response to heterogeneity across the entire region; and (2) to assess the detailed response of individuals and local populations to both natural environmental change and any experimental manipulations. Specimens are sorted and recorded using the Museum of Southwestern Biology (MSB) computerized information retrieval system.

Fertilization Studies

The abundance of plants from many different biomes suggests intriguing questions of nutrient limitation. Ecosystem nutrient limitation has been noted in many studies while others clearly indicate that each species responds individually to resource availability in relation to its requirements. The ability to predict strong El Niño or La Niña events offers additional capabilities to study nutrient

limitation. During wet springs associated with El Niños, cool season plants are expected to be limited by nutrients rather than moisture. The warm season grasses also would be nutrient limited during an El Niño year because of nutrient immobilization by spring growth of cool season grasses. In La Niña years both cool and warm season grasses should be more water limited than nutrient limited. Fertilization experiments on Sevilleta grasslands have been initiated to evaluate these hypotheses.

Wildfire Studies

Natural fires have become more common on the grassland areas of the protected research areas (no cattle grazing). The studies of these natural fires shows that the influence of fire is very species specific because perennial grasses with large, belowground root systems (for example, Blue Grama of the Great Plains flora) survive while Chihuahuan Desert species (for example, Black Grama, desert shrubs) are depleted. Thus, in the tension zone between Chihuahuan and other biomes, fire may be a primary agent in controlling species movement due to climate dynamics. In areas where the desert species have been established for a longer period (i.e., more like desert habitat than transition habitat), the grass component has been greatly reduced and fires are rare or nonexistent. The natural fires allow studies of species and the effects on subsequent ecosystem processes. Factorial experiments have been conducted that relate burning and herbivore (large ungulates) activity to plant and animal community composition and ecosystem processes.

Future Research Potential

Based on current research activity in the Sevilleta region, as well as on the research activity projections considered internally and with potential visiting researchers, several major avenues of future research are anticipated. First are ecosystem- and community-level studies addressing the effects of climate change on biotic systems. These will include both seasonal, annual, decadal (and longer time scales) fluctuations and trends in climatic variables, and the eventual responses in ecosystem structure and function among the various biomes represented in the Sevilleta region.

Second, a dramatic increase in population- and organism-level studies can be expected in response to the increasing concern about world-wide patterns of declining biodiversity. Included in this category of research are studies concerning the genetic variability of existing plant and animal species, and the historical implications. As mentioned above, the Sevilleta is an extremely species-rich region, and many species therein occur near the boundaries of their range distributions. As such, they are subjected to environmental conditions that, for them, may be extreme. In some cases, for example, a species of desert millipede, the region contains only isolated, relict populations that are widespread elsewhere. Comparisons of genetic similarity among these and other species populations that, over time, have colonized marginal habitats in the Rio Grande Basin, will be of prime importance in LTER studies.

Third, an increase in the number of studies concerning the relationship between ecosystem restoration and biodiversity

is anticipated. The Rio Grande Basin as a whole has been overexploited in a number of ways, particularly in the past century. Currently, however, much discussion and some research has centered on restoration of the region's semi-arid grasslands and on the marshes and gallery forests associated with the Rio Grande itself. The Sevilleta NWR contains extensive grasslands that have been free of livestock grazing for nearly two decades. Studies of the effects of livestock removal on the diversity of grassland biotas are underway and more are planned. The Rio Grande Valley has lost most of the marshland that made it one of North America's most important migration routes for birds. The introduction of salt cedar and Russian olive trees in this century has greatly compounded that loss in terms of habitat alteration. Significant strides to correct these alterations have been made by the Fish and Wildlife Service at the Bosque del Apache NWR, where federal and UNM biologists have begun collaborative studies on restoration of the original wetlands.

Fourth, a number of current and planned research projects on the Sevilleta concern the research and development of new technologies for use in ecological studies, and the application of current technologies to field research. For example, the development of field FTIR (Fourier-Transform Infra-Red) technology to measure trace atmospheric gas production over km² areas of natural ecosystems has been and continues to be an active program on the Sevilleta. In addition, Sevilleta researchers are developing a 3-dimensional, advanced image processing system that will calculate plant biomass from stereoscopic photographs of permanent study plots. An example of integration of existing technologies is the collaborative effort between UNM and NMIMT to correlate lightning activity during thunderstorms with realized precipitation. A 20 km² grid of 25 tipping-bucket rain gauges, each gauge instrumented with a data logger, provides rainfall timing and distribution data that are integrated with temporal and spatial lightning data collected simultaneously by Langmuir's Lightning Detection System. As future technology is made available for scientific use, Sevilleta LTER researchers will continue to develop practical applications of technology for ecological research.

Educational Activities: REU and UMEB Programs

The Sevilleta Research Experiences for Undergraduates Program and the Undergraduate Mentorships in Environmental Biology Program continues to operate in collaboration with the Sevilleta LTER. As in prior years, the goals of these programs are to (1) instruct undergraduates in the principles of scientific research, (2) expose the students to a wide variety of ecological research techniques and career opportunities, (3) facilitate individual student research projects, and (4) encourage students to continue their scientific education in upper-division courses and graduate school. To accomplish these goals, the programs include (1) orientation meetings and a seminar series devoted to the variety of scientific opportunities in ecological research at the Sevilleta, (2) faculty-student one-on-one instruction of hypothesis development and research protocols in ongoing Sevilleta LTER projects, (3) field and laboratory experiences in sampling and data collection, (4) implementation of

individual student research projects, carried out under the guidance of student-selected faculty members, (5) a Sevilleta REU Symposium for project presentations by the students, (6) attendance at scientific meetings, and (7) preparation and submission of project manuscripts to scientific journals. These activities integrate all theoretical and technical aspects of the LTER and promote a holistic approach to large-scale ecological studies.

Applications of Sevilleta LTER Databases

The following is a brief description of how Sevilleta LTER results to date have been incorporated by agencies, resource planners, etc., into their management plans or processes.

(1) Public Health — Hantavirus: Sevilleta LTER data have been used by Public Health officials and the Federal Centers for Disease Control and Prevention in assessing the causes and circumstances of the 1993 Hantavirus epidemic in the Southwest. In addition, the CDC continues to collaborate with the Sevilleta LTER, via a separate grant to Co-P.I. Terry Yates, to monitor rodent populations and hantavirus prevalence in wild rodents.

(2) Land Management — Fire ecology: LTER studies of ecological responses to fires in Sevilleta's grasslands have yielded data on plant and animal survivorship and recolonization. These data have convinced the Fish and Wildlife Service to discontinue fire suppression in grassland/shrubland areas of the refuge, and allow lightning-caused fires to burn in a natural fashion. FWS will continue to stop fires in woodlands, but they have recognized the value of fires in grasslands in maintaining open grass habitats and curtail shrub invasions and desertification.

(3) River Management — Flooding on the Rio Grande: With additional funding from FWS, UNM Biologists Cliff Crawford and Manuel Molles are investigating the role of artificial flooding in restoration efforts along the Rio Grande. Floods are essential for reseeding cottonwood forests, and influence various ecosystem processes, such as wood and leaf litter decomposition and soil nutrient cycling. Sevilleta LTER data from the LTER site at Bosque del Apache NWR are being used in this project. Results from the study are being incorporated into the river management plan by the various state and Federal agencies responsible for flow regulation of the Rio Grande.

(4) Water Use Policies — El Niño: LTER researchers have provided to the public and the state and local governments a continuous stream of data on the ecological and hydrological effects of the El Niño - Southern Oscillation (ENSO) dynamic in New Mexico. Considerable press and TV news coverage has raised the public awareness of the ENSO phenomenon, and some planning decisions by the State Water Engineer have been based on ENSO predictions (for example, reduction of irrigation water allowances in 1992 after sufficient water was predicted during the El Niño of that year; extra water was allowed to flow to Texas, to pay off part of New Mexico's water debt).

(5) Rangeland Resource Use — Grazing Issues: LTER studies of livestock grazing on private rangeland adjacent to the Sevilleta NWR have been incorporated into the ongoing debate on use of western Federal lands for grazing. Policies on grazing are currently being considered at Federal and State levels.